# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

# THESIS

A VHF-FM DIGITAL SELECTIVE CALLING SYSTEM
MATHEMATICAL MODEL
USING GRADE OF SERVICE CRITERIA

by

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SEPTEMBER 1985

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# A VHF-FM Digital Selective Calling System Mathematical Model Using Grade of Service Criteria

by

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This thesis presents a mathematical model of a maritime VHF-FM Digital Selective Calling (DSC) System using grade of service as a criterion to determine if a single DSC channel can accommodate both distress and commercial calling. The model calculates the probability of a call being delayed, the average delay of a call, the probability of a call being answered within a certain time frame, and the throughput for the random access calling systems of ALOHA, Slotted ALOHA, Slotted ALOHA with Capture, Nonpersistent Carrier Sense Multiple Access (CSMA), and 1-Persistent CSMA. Analysis of the results indicates that all VHF DSC calling can be made on a single channel. Without regard to a cost-benefit evaluation, it was also determined that 1-Persistent Carrier Sense Multiple Access was the superior random access calling system to utilize for the VHF-FM Digital Selective Calling system.

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# I. MARITIME MOBILE DIGITAL SELECTIVE CALLING SYSTEM

The establishment of communications between shore and ship stations, and between ships has become markedly difficult due to increased maritime activities, limited radio officer watch periods, radio propagation characteristics, and limited availability of radio frequencies [Ref. 1:p.1]. Delays of 6 to 18 hours are not uncommon. The Digital Selective Calling (DSC) System has been developed to alleviate the problems of establishing communications while providing means for a global maritime distress system. The current recommendation for a VHF-FM DSC system has designated one radio channel to be used exclusively for distress and safety calling, and another channel to be used for commercial calling. The recommendation, based on a maximum channel loading (G) of 0.1 Erlang [Ref. 2:p. 2], may not be practical since there is only limited availability of radio frequencies and the use of one exclusively for distress may be inefficient. This thesis develops a mathematical model of a VHF-FM Digital Selective Calling System based on several grade of service criteria, instead of channel loading, to determine if a single DSC channel can accommodate both distress and commercial calling.

A general history of digital selective calling, as well as current communications methods used by the maritime mobile

service, is presented in this chapter. The operational and technical characteristics of the proposed international DSC system follow in Chapter II. Chapter III contains a description of various methods used to gain access to a radio channel called random access calling systems. The current model used to determine the number of required calling channels is shown in Chapter IV. The author's proposed mathematical model, along with various grade of service calculations, are presented in Chapter V. Finally, Chapter VI contains the conclusions and recommendations.

## A. BACKGROUND

Communications are carried out over frequency bands allocated to the maritime mobile service by the International Telecommunication Union (ITU). Morse Code telegraphy (CW) has been used since the beginning of maritime communications because of its ability for transmission and reception under almost any atmospheric conditions. However, CW has fallen out of favor because of three major reasons: [Ref. 3:p.77]

(1) The transmission of a message is a slow, manual process.

(2) It may take a long period of time to make the initial contact with a ship in order to send a message.

(3) It requires the use of separate distress frequencies.

The development of a system to improve communications calling has long been recognized as being essential to the maritime community. Studies into this area have revolved

around the use of autoalarms, radio-teletype (RTTY), tone-selective calling (SSFC), and satellite communications. While the bulk of future maritime communications traffic is expected to be carried by commercial satellites, the need for a global emergency system which did not require human monitoring and was simple to use predicated the development of a digital selective calling system [Ref. 3:p. 77].

Digital selective calling is designed to use the techniques of digital transmission for the establishment of communications, or for the passing of distress and safety information. Once the receiving station has been alerted by the DSC call that traffic pends, further communications are conducted on designated "working" channels. These "working" channels could be another DSC channel or they could be any other type of communication method available, (e.g. HF voice, VHF-FM radiotelephone, etc).

The current CCIR recommendation for a VHF Digital Selective Calling system has designated one channel to be used exclusively for distress and safety calling, and another channel to be used for commercial calling. The exclusive channel for distress and safety calling is based on the establishment of 0.1 Erlang as the maximum traffic loading for a DSC calling channel in order to achieve the grade of service required for distress calling [Ref. 2:p.2]. The maximum channel loading was chosen as 0.1 Erlang because, for

random access calling systems such as the University of Hawaii's ALOHA system, a call becomes delayed an exponentially increased period of time as the channel load increases beyond about 0.1 Erlang. Figure 1 shows this delay versus channel loading situation for two random access calling systems, ALOHA and Slotted ALOHA.

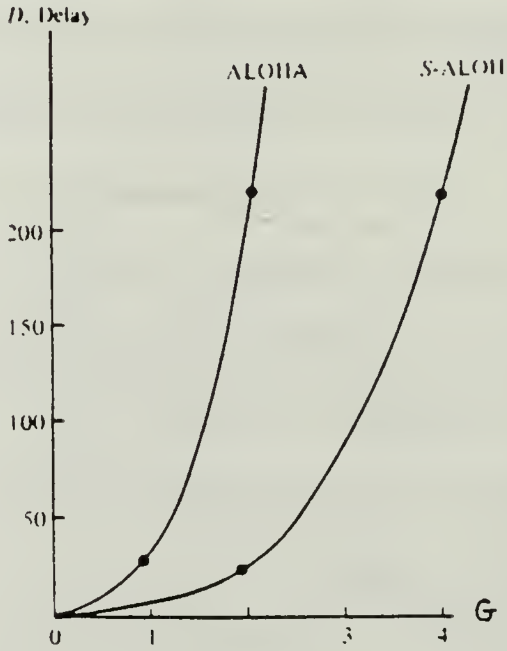



Figure 1. Delay as a Function of Channel Load

Submissions to the Interim Working Party of the ITU's International Radio Consultative Committee (CCIR) theorized a worst-case situation based on the number of VHF working channels indicated in Appendix 18 to the ITU Radio

Regulations (e.g. 28 working channels in total) [Ref. 2:p.8]. It was indicated that the maximum capacity of a single working channel would be 0.8 Erlangs [Ref. 4:p. 18]. Preliminary calculations based on the Erlang channel loading factor suggested that this level of operation might be supported by a single DSC channel [Ref. 4:p.22]. However, the traffic intensity should not dictate the grade of service (probability of finding the calling channel busy) because in some circumstances it prevents efficient channel utilization. For example, designating the channel loading limits the number of calls that may be placed on that channel. If more callers desire access to the calling channel than the loading permits, two or more channels would have to be allocated to service their needs, regardless of any other parameters such as the delay on calls through the calling system, or the probability that a call will reach its destination. The grade of service parameters listed in Table 1 can be important in designing a VHF-FM DSC system and as such will dictate the channel loading allowed on the channel. Therefore, a mathematical model for a VHF DSC system will be formulated based on the grade of service factor. This model will then be used to calculate the maximum allowable traffic

volume on a radio calling channel given a particular grade of service.

TABLE 1

GRADE OF SERVICE PARAMETERS

1. Probability of delay exceeding a specified amount of time.
2. Probability of delay.
3. Average delay of all calls through the system.
4. Channel Throughput

## B. CURRENT MARITIME COMMUNICATIONS METHODS

At the present time, there are three generally used classes of communications emissions. These are VHF-FM marine radiotelephone, HF single side band radio, and EHF satellite radio. Morse Code, which used to be the mainstay of maritime communications, is, in the author's opinion from experience with Coast Guard communications stations, infrequently used in today's mobile maritime service.

### 1. VHF-FM Radiotelephone

The range of a VHF-FM marine radiotelephone is limited to 50-60 miles [Ref. 5:p. 2]. The ship station must be within that distance of a coastal station in order to have telephone communications ashore. The basic coastal stations used for transmissions ashore are marine radio operators and U.S. Coast Guard stations. VHF-FM usage has grown so fast

that there are insufficient ITU Radio Regulation Appendix 18 frequencies for today's environment [Ref. 6].

In addition to voice communications, VHF-FM is being used for tone-generated selective calling in some limited geographical areas such as the Great Lakes and Mississippi River. This selective calling system, Sequential Single Frequency Code (SSFC) was placed into service in 1972, but never became widely used because of the severe limitations listed below [Ref. 3:p. 76]:

(1) The potential number of future subscribers can not be accommodated.

(2) SSFC is limited to full voice bandwidth operation.

(3) A call can not be prioritized.

(4) SSFC is unable to propose the use of other working frequencies while the call is in remote control at the receiving end.

### 2. HF Single Side Band Radio

HF is currently used for radio teleprinting (SITOR), radio telephony, and automatic distress and safety alerting (AUTOALARM). HF signal characteristics have made it an excellent vehicle for long haul communications, filling the gap between VHF-FM range and a range of up to several thousand miles. However, HF is limited by propagation phenomena and atmospheric disturbances which can affect its performance. There are also few coastal stations operating on HF frequencies and the number of ship stations wanting to use

them is in the thousands. The Coast Guard indicated in a report that for ships on the high seas, the average time required to contact a ship station was in excess of 6 hours [Ref. 5:p. 1E2].

### 3. EHF MARISAT/INMARSAT

The Maritime Satellite Organization (MARISAT) and the International Maritime Satellite Organization (INMARSAT) provide satellites necessary for improving maritime communications, thereby assisting in improving distress and safety communications, efficiency and management of ships, and maritime public correspondence services [Ref. 8:p. 2].

Using EHF frequencies and an installed satellite terminal, ship stations are connected into the public switched telephone network and Telex services via a satellite and through a number of coastal earth stations. Three orbiting satellites provide coverage in the Pacific, Atlantic, and Indian ocean regions. It was projected that over 2100 ship subscribers would be operating on this system by 1988 [Ref. 8:p. 6]. The high initial investment required to purchase terminals and equipment prohibits many potential customers from using MARISAT/INMARSAT [Ref. 9].

## C. DIGITAL SELECTIVE CALLING (DSC) SYSTEM

Selective calling systems were described as early as the ITU's Ninth Plenary Assembly of the International Radio Consultative Committee (CCIR, 1959). Improvements to the ways

in which maritime calling was performed were clearly required. As a result of the CCIR assembly, the Federal Republic of Germany and the United States conducted tests on selective calling systems. These tests and further tests were studied in the 1963 and 1966 Plenaries by a study group of the CCIR [Ref. 1:p. 2].

The World Administrative Radio Conference (WARC, 1967) amended the ITU Radio Regulations to permit the use of maritime selective calling and adapted the German-developed Sequential Single Frequency Code (SSFC) system to meet immediate operational requirements. The United States did not support the SSFC system because it was not suitable for all classes of radio emissions, e.g. HF and VHF, in the maritime mobile service [Ref. 1:p. 2]. The ITU also called for the development of a system with greater capability for future maritime use. The four major areas of concern using the SSFC tone-generated selective calling technique were [Ref. 3:p. 76]:

(1) The potential number of future subscribers can not be accommodated.

(2) SSFC was limited to full voice bandwidth operation.

(3) Prioritizing a call could not be done.

(4) SSFC was unable to propose the use of other working frequencies while the call was in remote control at the receiving end.

The United States proposed at the 1967 World Administrative Radio Conference and again at the CCIR Interim

Meeting in 1972 that digital selective calling techniques should be adopted. Because the United States could not produce experimental data supporting its claims, the proposal was denied. After the 1972 CCIR meeting, the U.S. Maritime Administration initiated the development and testing of a DSC system. The results of this effort are listed in Figure 2 and show that digital selective calling is capable of satisfactory operation in the maritime frequency bands of HF, MF, and VHF [Ref. 1:p.91].

The CCIR, in its 1974 meeting, recommended the adoption of a DSC system much like the one proposed by the United States. Later that year, the 1974 WARC established dedicated DSC frequencies. The ITU's Fourteenth Plenary Assembly of the CCIR (CCIR, 1978) approved Recommendation 493-1 which contained the operational and technical characteristics of the DSC system [Ref. 10:p. 2-2]. Finally, the Fifteenth Plenary Assembly of the CCIR (CCIR,1982) adopted the DSC operational and technical characteristics contained in CCIR Recommendation 493-2 and the DSC operational procedures in CCIR Recommendation 541-1 [Ref. FCC]. These last recommendations were slight modifications of the 1978 approved operational and technical characteristics.

A parallel study in the area of maritime distress communications had been ongoing since 1979 when an International Conference on Search and Rescue adopted a new

| FREQUENCY LOCATION DIRECTION OF TRANSMISSION | DATA RATE (Baud) | SELECTIVE CALLS SENT | SELECTIVE CALLS RECEIVED (2 addresses compare) | % | SELECTIVE CALLS RECEIVED (1 or 2 addresses compare) | % |
|---|---|---|---|---|---|---|
| HIGH FREQUENCY | | | | | | |
| KMI-S.S. MONTEREY | | | | | | |
| Shore-to-Ship | 75 | 876 | 615 | 70 | 647 | 74 |
| | 150 | 4,615 | 3,405 | 74 | 3,884 | 84 |
| TOTAL | 75 & 150 | 5,491 | 4,020 | 73 | 4,531 | 83 |
| Ship-to-Shore | 75 | 255 | 224 | 88 | 239 | 94 |
| | 150 | 2,429 | 1,331 | 75 | 2,057 | 85 |
| TOTAL | 75 & 150 | 2,684 | 2,055 | 77 | 2,296 | 86 |
| NMH-USCG CUTTERS | | | | | | |
| Shore-to-Ship | 75 | 93 | 57 | 61 | 66 | 71 |
| | 150 | 6,945 | 5,244 | 76 | 5,613 | 81 |
| TOTAL | 75 & 150 | 7,038 | 5,301 | 75 | 5,679 | 81 |
| Ship-to-Shore | 150 | 4,710 | 3,289 | 70 | 3,699 | 79 |
| HF TOTAL | 75 | 1,224 | 896 | 73 | 952 | 78 |
| | 150 | 18,699 | 13,769 | 74 | 15,253 | 82 |
| | 75 & 150 | 19,923 | 14,665 | 74 | 16,205 | 81 |
| MEDIUM FREQUENCY | | | | | | |
| NMF-USCG CUTTERS | | | | | | |
| Shore-to-Ship | 150 | 701 | 651 | 93 | 677 | 97 |
| Ship-to-Shore | 150 | 532 | 404 | 76 | 472 | 89 |
| MF TOTAL | 150 | 1,233 | 1,055 | 86 | 1,149 | 93 |
| VERY HIGH FREQUENCY | | | | | | |
| NMH-USCG CUTTERS | | | | | | |
| Shore-to-Ship | 600 | 2,058 | 1,964 | 95 | 1,977 | 96 |
| Ship-to-Shore | 600 | 1,750 | 1,734 | 99 | 1,735 | 99 |
| | 1,200 | 184 | 160 | 87 | 160 | 87 |
| TOTAL | 600 & 1200 | 1,934 | 1,894 | 98 | 1,895 | 98 |
| VHF TOTAL | 600 | 3,808 | 3,698 | 97 | 3,712 | 97 |
| | 1,200 | 184 | 160 | 87 | 160 | 87 |
| | 600 & 1200 | 3,992 | 3,858 | 97 | 3,872 | 97 |

FIGURE 2. Summary of DSC Test Results

Search and Rescue Convention. This Conference asked the International Maritime Organization (IMO) to develop a global maritime distress and safety system to provide the telecommunications for the International Convention on Maritime Search and Rescue [Ref. 12]. In the fall of 1980, the IMO proposed its Future Global Maritime Distress and Safety System (FGMDSS). The FGMDSS was to be developed on the principles of digital selective calling which meant that short-wave CW communications would no longer be used for distress [Ref. 3:p. 78]. IMO's announcement concerning the FGMDSS provided a strong impetus for the development of a DSC system.

In the fall of 1983, worldwide testing of the final DSC system was conducted on the HF frequencies. Figure 3 provides the results of the testing. CCIR Interim Working Party (IWP) 8/10, which has overall responsibility for the development and implementation of the DSC system, considered the results of the trials impressive. The IWP also pronounced that the DSC system was a viable system for alerting distress cases by terrestrial radio-communication [Ref. 13].

This introduction and short history of digital selective calling should leave the reader with a basic understanding of why DSC is an important step forward in the area of maritime communications. In the next chapter, the operational and technical aspects of the DSC system will be discussed.

DSC Success Probabilities During Trials

| Transmitting Station | Dates 1983 | Call attempts | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Single Frequency (MHz) | | | | | Multi-frequency | Composite |
| | | 4 | 6 | 8 | 13 | 17 | | |
| Rogaland | 17/10 | 46/46 | 45+1/46 | 41+4/46 | 43+3/46 | 40+3/46 | 220/230 | 45/46 |
| Portsmouth | 18/10 | 0/0 | 9+3/24 | 11+1/24 | 20+1/24 | 21/24 | 94+9/120 | 24/24 |
| Sydney | 20/10 | 32/46 | 27+1/40 | 6/46 | 38/40 | 37/40 | 217+1/230 | 45/46 |
| Tokyo | 21/10 | 16/16 | 15+1/16 | 16/16 | 15/16 | 15+1/16 | 80/80 | 16/16 |
| Guam | 22/10 | 0/0 | 46/46 | 44/46 | 46/46 | 42+1/46 | 230/230 | 46/46 |
| Portsmouth | 24/10 | 0/0 | 21+1/31 | 27+1/31 | 31/31 | 23+2/30 | 155/155 | 31/31 |
| Somerton | 25/10 | 43/43 | 43/43 | 43/43 | 43/43 | 40+2/42 | 221/221 | 42/42 |
| Tokyo | 27/10 | 16/16 | 16/16 | 16/16 | 16/16 | 14/16 | 80/80 | 16/16 |
| Guam | 29/10 | 0/0 | 38/42 | 31/42 | 39/42 | 34+1/42 | 200/210 | 40/42 |
| Somerton | 31/10 | 45/45 | 45/45 | 46/46 | 46/46 | 46/46 | 228/228 | 43/43 |
| Izu | 1/11 | 16/16 | 15/16 | 15/16 | 16/16 | 15+1/16 | 80/80 | 16/16 |
| Izu | 4/11 | 16/16 | 16/16 | 16/16 | 16/16 | 16/16 | 80/80 | 16/16 |
| Rogaland | 5/11 | 46/46 | 46/46 | 45+1/46 | 42+3/46 | 38+7/46 | 230/230 | 46/46 |
| Norddeich | 7/11 | 45/46 | 46/46 | 43+1/44 | 41+2/44 | 38+3/44 | 229/229 | 46/46 |
| Somerton | 9/11 | 42/42 | 42/42 | 42/42 | 42/42 | 42/42 | 210/210 | 42/42 |
| Ivan Chernykh | 9/11 | 1/1 | 3/3 | 2/2 | 4/4 | 2+1/3 | 14/14 | 0/0 |
| Totals | | 365/379 | 473+7/518 | 444+8/522 | 499+9/518 | 464+22/515 | 2578+10/2627 | 515/518 |
| % of calls received without errors | | 96.31 | 91.31 | 85.06 | 96.33 | 90.10 | 98.13 | 99.42 |
| Additional % of calls received with errors but no errors in ID or coordinates | | | +1.35 | +1.53 | +1.74 | +4.27 | +0.38 | |

Entries: Call attempts successful/call attempts transmitted. A + indicates additional number of calls received with errors, but no errors in ID or coordinates.

Notes:

1) The USA stations (Portsmouth and Guam) did not transmit on 4 MHz.
2) In cases where an analysis of receivers logs casts doubt upon a given transmitter performance, the transmitter was, nevertheless, assumed to have performed correctly and the resulting low reception success rates were included in the above table. This table, therefore, represents a "worst case" analysis of the trial results. It is probable that these results underestimate the performance of the participating receiving stations.
3) The combined logs of all receiving stations indicated that there was a problem with S dney's scheduled transmissions on 8-11-1983. There were no propagation anomalies reported for that day, however no station received calls on 4, 6, 8, or 13 MHz. Only Japan received a few calls on 17 MHz during the early morning hours (UTC). Therefore, the IWP disregarded the data on 8-11-1983.

Figure 3. Worldwide HF DSC—Testing Results

## II. CHARACTERISTICS OF A DSC SYSTEM

### A. OPERATIONAL CHARACTERISTICS

The operational characteristics of a digital selective calling system must be compatible internationally, thus requiring a standardized format for message traffic. The recommended format of a call sequence (message format) adopted by the CCIR for the international DSC system consists of a format specifier, address, category, self-identification, message data area, and end-of-sequence block, each of which is explained below [Ref. 14:p. 1]. The format of a call sequence is shown in Figure 4.

| | | | |
|---|---|---|---|
| format specifier | address | category | self-identification |

| | | | |
|---|---|---|---|
| message 1 | message 2 | .... | end of sequence |

Figure 4. Format of a Call Sequence

A DSC call sequence is a one-way radio transmission and can be one of two types. A call alert sequence is initiated by a sending station indicating a desire to pass communications. A call acknowledgement sequence is sent by a receiving station, acknowledging receipt of a call alert

sequence. If the sending station has additional communications to pass, both the sending and receiving stations shift to a "working" channel to complete the transmissions.

1. Digital Selective Call Sequence Format

a. Format Specifier

The format specifier indicates whether the call is a "distress" call, an "all ships" call, or a call to a selective group of ships or stations. The selective group could consist of one ship or station, a group of stations having a common interest, or a group of ships in a specified geographical area. In addition, the format specifier might indicate the call is a special sequence for semi-automated or automated VHF/UHF services (e.g. marking sequences, signalling sequences).

b. Address

The address block specifies for whom the call is designated. The address information of distress and all ships calls will be contained in the format specifier block. For all other types of calls, the address will be the unique identification assigned to each called ship or station, or special identifiers assigned to a group of ships having a common interest or ships operating in a particular geographical area.

The digital selective calling system has been designed to have the selective address capacity for quantitatively meeting all of the international maritime selective call requirements for the foreseeable future.

c. Category

The category block of information defines the degree of priority of the call sequence. For a distress call this information is again contained in the format specifier block. All calls are prioritized within one of six categories:

(1) Distress.

(2) Urgency.

(3) Vital safety.

(4) Important safety.

(5) Ship business priority (the proposed definition is a call authorized by the ship owner or agent requiring immediate handling on the ship).

(6) Routine.

d. Self-Identification

This block simply contains the calling station's unique identification symbols.

e. Messages

There is a limit of 3 general messages allowed in a call sequence, with the exception of distress calls which have 4 messages. For a distress call, the distress

information is contained within four messages and appears in the following order:

(1) An indication of the nature of distress.

(2) An indication of the distress position.

(3) The time that the distress position was valid.

(4) The type of communication which is preferred by the unit in distress for subsequent exchange of communications.

2. <u>Types of DSC Call Sequences</u>

If the call sequence is not part of a distress call, then it will either be a telecommand call alert sequence or an acknowledgement call sequence. A telecommand call alert sequence contains information for setting up communications on another channel, or may include terminal control functions, transmitter and receiver control functions, or special purpose functions. An acknowledgement call sequence is simply a call to a sending station verifying that a DSC call alert sequence has been received.

## B. TECHNICAL CHARACTERISTICS

Paralleling the operational characteristics of the proposed DSC system are its technical characteristics. The technical characteristics maintain standardization in the international community in the areas of electrical engineering and communications by specifying the bit patterns to be used for each of the format blocks [Ref. 14:p.7].

1. Technical Format of the Call Sequence

The recommended technical format of a call sequence contains a dot pattern, phasing sequence, format specifier, address, category, self-identification, up to four message areas, an end-of-sequence block, and an error-checking character [Ref. 14:p. 23]. This format, with the exception of the dot pattern, phasing sequence, and error-checking character is the same as the operational characteristics format. The technical format of a typical routine message is presented in Figure 4.

a. Dot Pattern

As investigations continued into DSC, scanning devices were proposed by the Japanese so that a receiver could listen to more than one frequency [Ref. 10:p. 3-7]. To make use of a scanning device possible, it was necessary to add a signal which told the receiver to stop scanning. This is called the "dot pattern" which switches between "zero" and "one" bits for a period of 2 seconds. HF and MF digital selective calling signals begin with a two-second dot pattern. Dot patterns will not be used in acknowledgement sequence calls, ship-to-shore calls with the exception of distress calls, or VHF calls, unless more than one DSC channel is being used [Ref. CCIR 14:p. 9].

b. Phasing Sequence

The phasing sequence provides information to the receiver to permit correct bit phasing and unambiguous

determination of the positions of the signals within a call sequence.

The receiver phase synchronizes with the transmitter by recognizing a specific pattern of symbols rather than keying on a change in the dot pattern. This method of phasing was adopted in order to reduce false synchronization caused by a bit error in the dot pattern.

| Dot pattern | DX/RX Phasing sequence | Format specifier 2 symbols | Called party address 5 symbols | Category 1 symbol |
|---|---|---|---|---|

| Self ident 5 sym | Telecommand message 2 symbols | Frequency message 3 symbols | Frequency message 3 symbols | End of sequence 3 symbols | Error check char 1 symbol |
|---|---|---|---|---|---|

Figure 5. Technical Format of a Call Sequence

c. Error-check Character

The digital selective call is a synchronous call using a ten-bit error-detecting code. The first seven bits of the code are information bits representing the 128 symbols of the ITA No. 5 code or the ASCII code. Bits 8,9, and 10 are used for error detection.

2. Time Diversity

With the exception of the dot pattern and phasing signals, each signal in the DSC sequence is transmitted twice

in a time-spread mode. Imperfect propagation, interfering signals, and coincidence with other calls require this "echoing" effect to achieve satisfactory reception of the desired signal. The first transmission of a specific DSC signal could be followed by the transmission of four other DSC signals before the original signal is re-transmitted. The time interval, thus providing for time-diversity reception, for the signals is 400 milliseconds (msec) for HF and MF channels and 33 1/3 msec for VHF channels [Ref. 14:p. 7].

The frequency shifts and modulation rates for the three modes of transmission are:

(1) HF and MF channels will use a frequency shift of 170 hertz at a rate of 100 baud. When frequency-shift keying is effected by applying audio signals to the input of single-sidebanded transmitters, the center of the audio-frequency spectrum at the transmitter is 1700 hertz.

(2) VHF channels will use a frequency shift of 800 hertz at 1200 baud. The modulation technique is proposed to be audio (frequency-modulation) with frequency-shift keying of the modulating carrier frequency of 1700 hertz. Carrier Sense Multiple Access (CSMA) will be the access method utilized. CSMA access techniques are discussed in Chapter III.

## C. METHOD OF OPERATION

Digital selective calling (DSC) equipment operates in conjunction with the ship's radio equipment when installed onboard a ship, or in conjunction with the shore radio equipment when it is installed at a shore station. Although the exact description of the DSC unit will depend on its

manufacturer, the equipment will generally be self-contained including all necessary power supplies, modems, keyboards, controls, and displays for operation with the installed radio equipment.

The following description of a DSC unit and its operations is based on a DSC unit developed by the GTE Sylvania Corporation [Ref. 1:pp. 9-12]. The DSC unit for a mobile maritime station incorporates a microprocessor, the primary element of which is a central processing unit contained on a single integrated circuit. The operation of the unit is controlled by a program stored in the microprocessor's programmable read-only memory. Message processing and storage is accomplished with the microprocessor read/write memory. A functional block diagram of a Digital Selective Calling unit is depicted in Figure 6.

A selective call message that is to be transmitted is composed using a typewriter-like keyboard and is displayed on a cathode-ray tube terminal. The operator has full editing capability and can make corrections prior to message transmission. After the message has been prepared in the proper operational and technical formats of CCIR Recommendation 493-2, it is transmitted as a serial data stream. The DSC output is a binary Audio Frequency Shift Keyed (AFSK) signal that is encoded with the message. The DSC unit automatically initiates transmitter keying and following detection that the channel is clear, the AFSK signal is

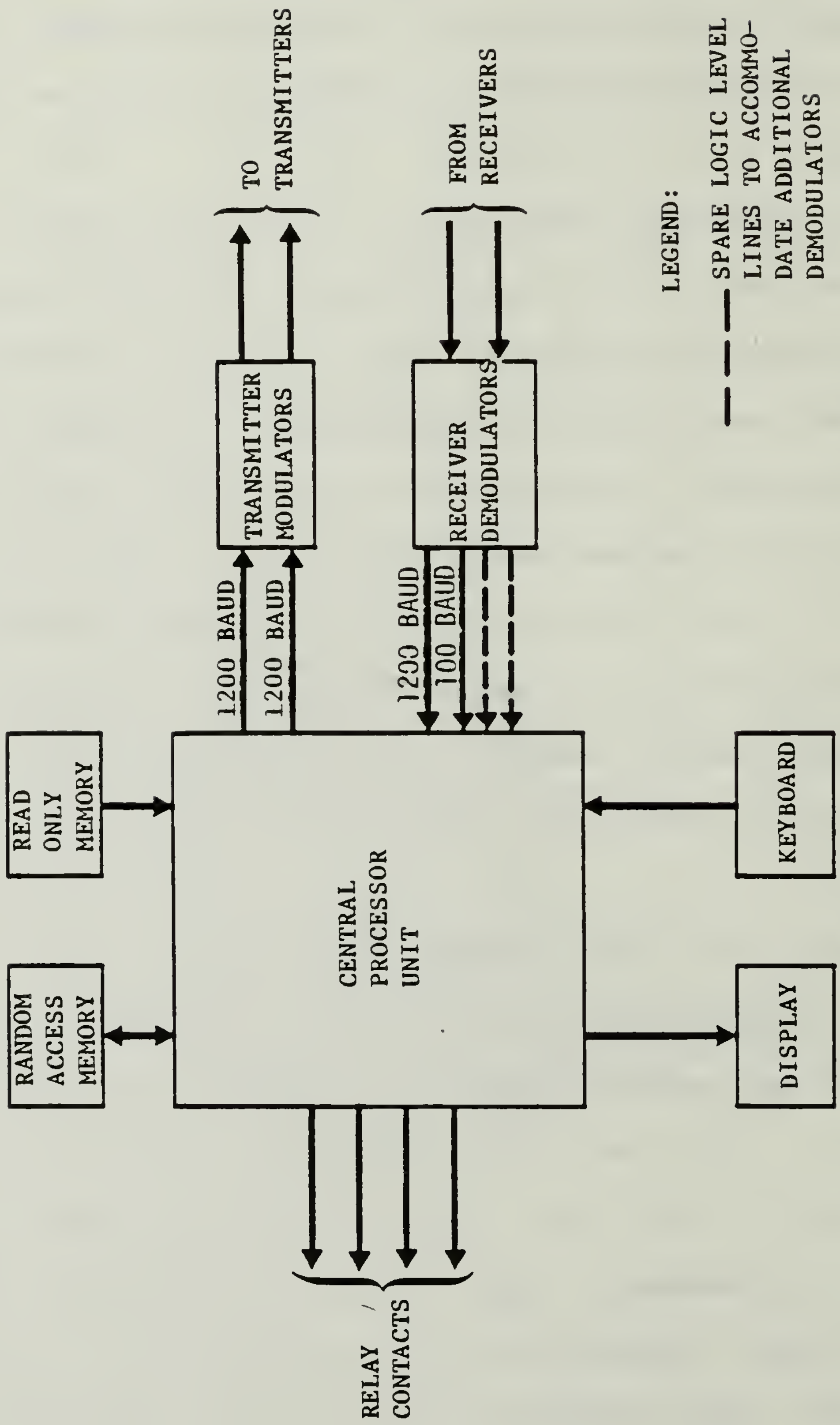



Figure 6. Functional Block Diagram of a DSC Unit

applied to the transmitter output. Modems are interfaced with the standard communications transmitters and receivers. These modems are switch selective for transmission, accommodating all classes of emission or frequencies assigned for mobile maritime communications.

Receiving the DSC AFSK signal is essentially the reverse of transmitting a message. The modem outputs are continually monitored for the presence of the dot pattern or phasing sequence. When these are detected, the DSC unit decodes the signal and temporarily stores it in random access memory. At present, the buffer is designed to store two incoming DSC messages [Ref. 15]. The address block is compared to the station's address or one of the special identifiers assigned to a group of stations. If the comparison indicates the message is destined for the station, appropriate aural or visual alerts, or remote telecommand functionings are enabled. If the message is not intended for the receiving station, it is cleared from the buffer and the DSC unit stands ready to receive the next message.

In order for the message/call sequence to be transmitted and received in a broadcast radio network, as the maritime mobile service environment is, there are numerous methods available that the transmitting site could use to gain access to the transmission medium. These methods, called random access calling systems, are discussed in the next chapter.

# III. RANDOM ACCESS CALLING SYSTEMS

## A. INTRODUCTION

Broadcast networks in general, and packet radio networks in particular, are composed of transmitter and receiver sites which communicate on a common frequency. The signal strength of one site is usually of such power that it can only transmit to a small subset of the other sites in the network. The typical broadcast network site operates in the asynchronous mode by transmitting to every site within its range whenever it has a message. When a receiving site is in the range of two transmitting sites, a collision of the two messages occurs and neither message is correctly received. Similarly, a transmitting site cannot send and receive a message concurrently. For most broadcast networks, in which every site can transmit directly to all other sites, the networks are constrained to have at most one successful radio transmission at a time. Networks in which multiple users share a common communications channel in a way that can lead to conflicts are widely known as contention networks. The best known network of this type is called the ALOHA network.

Allocating a single communication channel among competing users happens in many different types of networks. One common situation in which a single channel is shared is a

multidrop line connecting a group of users. A user is polled by a central site giving the user a chance to send any messages it might have. Which users the central site should poll is a major problem in this type system. If a polling network has hundreds or thousands of users, only a small fraction might have a need to transmit at any given moment. Frequency-division multiplexing (FDM) is another method of allocating a single channel among a number of users. If there are N users, the channel bandwidth is divided up into N equal portions, with each user being assigned to one of the portions. Since each user has his own frequency to transmit, there is no interference between users, and the network can operate without any collisions. However, when there is a large number of stations which come and go as they please, FDM poses a few major problems. A large piece of the channel bandwidth may be wasted if less than N users are using the channel, and if more than N users want to use it some of them will be denied access. In addition, most computer data traffic is extremely bursty (peak traffic to mean traffic ratios of 1000:1 are common) and as such most of the channel will be idle most of the time [REF. 16:p. 252]. A last example of how a channel might be allocated among competing users is the Asynchronous time-division multiplexing (ATDM) concept. Each user is given its own dedicated port into a concentrator which then feeds into the central site. If two users send traffic simultaneously, the concentrator handles

the situation by placing each user's data into different memory locations within the concentrator. The data is transmitted from the concentrator when the channel is clear. In an environment such as the maritime mobile service, with uncoordinated, geographically dispersed users who have only a single shared channel to communicate on, there is no private port, and two simultaneous transmissions will collide. Giving each user a portion of the bandwidth to work with is just the FDM technique which was discussed earlier, which was determined to be too inefficient with many bursty users. Therefore, the aforementioned techniques are not suited for the VHF-FM DSC system.

## B. ALOHA TYPE CALLING SYSTEMS

### 1. Pure ALOHA

In the early 1970's, Norman Abramson and his co-workers at the University of Hawaii developed the ALOHA system to solve the problem of allocating a single communications channel among competing users [Ref. 17]. ALOHA was the first computer system to employ radio techniques instead of point-to-point wires for its communication facility. The ALOHA network works on the following principle: users are allowed to transmit on a totally random basis (Pure ALOHA) whenever they have data to pass. A sketch of packet generation in an ALOHA network is

given in Figure 7. A packet is synonymous to a DSC call sequence. All of the packets are the same length because it has been shown that the throughput of ALOHA networks is maximized by having a uniform packet size rather than allowing variable length packets [Ref. 18]. Some of the message packets will collide with one another, destroying them. However, due to the perfect feedback property of packet broadcasting, the sender of a packet can always find out whether or not his packet was destroyed [Ref. 16:P. 253]. If the packet was destroyed, the sender waits a random amount of time before re-transmitting the same packet. The vulnerable period of a packet is shown in Figure 8.

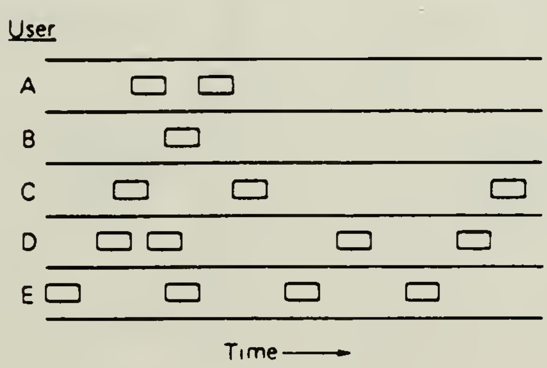



Figure 7. Packet Generation in an ALOHA Network

a. Capacity and Delay of the ALOHA Network

The throughput (S) will first be determined by assuming that channel loading (G) is the total number of messages or packets per second to be delivered. This value

is the current packet demand on the channel, measured in packets per second. Packet time will be defined as the amount of time required to transmit the fixed-length packet. Again, the fixed-length packet is necessary for maximum throughput. The user population is assumed to be an infinite set, generating K new packets according to a Poisson distribution with mean S packets per packet time. (The infinite-population assumption is necessary to ensure that S does not decrease as users become blocked.) In addition to new packets, the users also generate retransmissions of packets destroyed by collisions. The probability of K

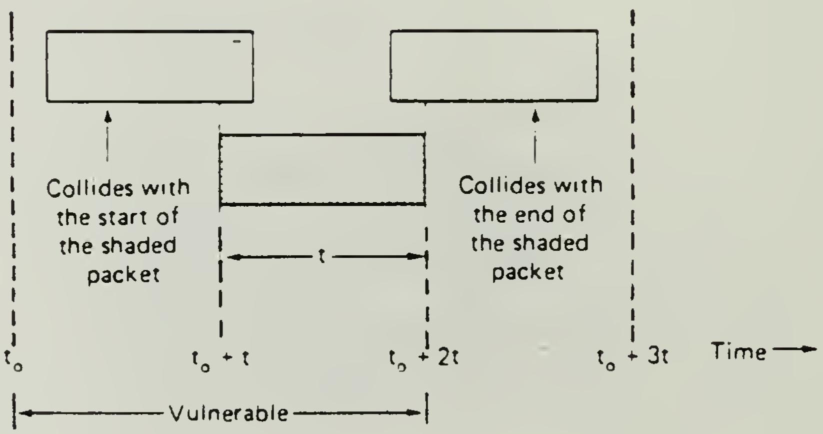



Figure 8. Vulnerable Period of a Packet

packets arrivals per packet time, is also Poisson distributed, with a mean of G packets per packet time. At low load conditions ($S \approx 0$), there will be few collisions, few retransmissions, so $G \approx S$. Under heavy loading conditions there will be numerous collisions so $G > S$. Under all loads,

the throughput is just the offered traffic, G, times the probability of a transmission being successful ($S = GP_0$), where $P_0$ is the probability that a packet does not suffer a collision.

A packet does not suffer a collision unless another packet is generated during the time the first packet is being transmitted. The probability that K packets are generated during a given packet time is Poisson distributed. This indicates that the probability of zero packets being generated during a given packet time is also Poisson distributed and is equal to exp (-G), obtained by replacing K with zero in the equation below. The use of (exp) in this thesis will mean the exponential function. The expression exp (-G) means the exponential function raised to the (-G) power. The Poisson process is based on the assumption that there is an infinite population of statistically unrelated calls and/or callers. Telecommunication network theory uses the Poisson process frequently to describe the generation and interarrival of calls within the system [Ref. 19:p. 64]. The Poisson equation is given below where G is the channel loading measured in Erlangs.

$$P(K) = \frac{G^K \exp(-G)}{K!}$$

In an interval of two packet times (refer to Figure 8), the mean number of packets or channel loading

generated is 2G. The probability of no other traffic being generated during the 2 packet length time is again given by the Poisson equation: [Ref. 16:pp. 255-256]

$$P(0) = P(K=0) = \exp(-2G)$$

Using S = GP , the throughput is then calculated to be:

$$S = G \exp(-2G)$$

This result was first derived by Abramson in 1970. The value G in the last equation is the total traffic seen by the communication channel which includes not only the current packet demand on the channel but all the packets re-transmitted because of collisions as well. This last probability, P(K=0), is that of a particular user's packet being successfully transmitted to the receiver site.

The throughput-offered traffic load relation is shown in Figure 9. As the channel traffic begins to increase, the useful throughput begins increasingly relatively quickly. The probability of collisions also increases rapidly resulting in a lower probability of successful transmission. At a value of G equal to one-half,

any further increase in traffic creates collisions with such a high probability that the useful throughput is actually reduced. The point of maximum useful throughput, known as the ALOHA channel capacity, occurs at a value of channel traffic of G = 0.5. The useful channel throughput is S = 1/(2e) = 0.184. This states that the best channel utilization obtained with Pure ALOHA is 18.4% of the original channel bit rate. This occurs when the channel is filled to

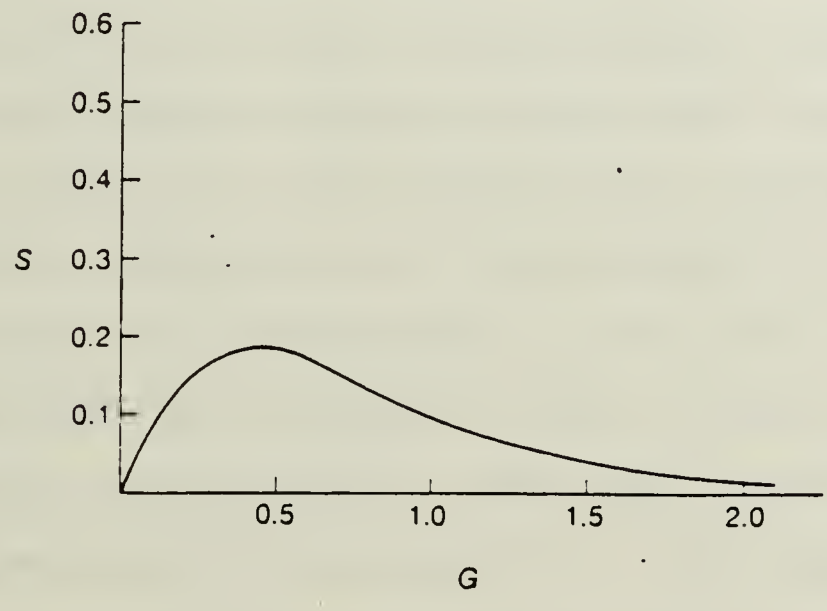



Figure 9. Channel Throughput Versus Channel Load in an ALOHA Calling Channel

50% (G = 0.5) of its bit rate with transmitted traffic [Ref. 19:p. 223]. Although the useful throughput is only 18.4%,

the ALOHA network throughput is composed of only useful delivered information. A 50,000 bit per second channel would have a useful throughput of about 9200 bits per second, and if the average demand of a single user was only a few bits per second, the channel could support possibly as many as 5000 users [Ref. 19:p. 223].

Delay through a Pure ALOHA network is defined as the time interval from when a user node is ready to transmit a packet until when it is successfully received by the receiving node. This delay encompasses the queueing delay, propagation delay, and transmission time. In ALOHA systems the queueing delay is equal to zero because a user transmits immediately when it has a packet to send. However, because of collisions, the queueing delay time may be considered the total time consumed prior to a successful transmission, (i.e. the total time spent in unsuccessful transmissions). First, the value of the expected number of transmissions per packet is necessary. This simply is the channel load divided by the throughput, G/S. The value of S is the amount of traffic that is ultimately delivered successfully, regardless of how many times it has to be repeated. The value of G is the total traffic in the channel, which is the successful throughput plus all the previously unsuccessful packets. The ratio of G/S then represents the average number of times each packet has to be transmitted before being successfully

delivered. Since there is only one successful transmission required, the number of re-transmissions per packet is the average number of transmissions (G/S) minus 1 successful transmission. The full equation is:

$$G/S - 1 = \exp(2G) - 1$$

The delay through the system is derived from this value. The average number of re-transmissions is multiplied by the average delay encountered for one re-transmission. This average delay encountered by one re-transmission is developed as follows: a common normalized algorithm used for ALOHA is to re-transmit after a time selected from a uniform distribution of from 1 to K packet-transmission times [Ref. 20:p.294]. The average delay is then (k + 1)/2. To this is added the amount of time a station must wait to determine that its packet was unsuccessful. This is just the time it takes to complete a transmission, (1 + N), plus the time it takes for the receiver to generate an acknowledgement (w) plus the propagation time for the acknowledgement to reach the station, (N). In Pure ALOHA, the vulnerable period is 2 packet lengths, 2(1 + N). The throughput equation and delay equation after all this look like:

$$S = G \exp[-2(1+N)G]$$

$$\text{Delay} = [\exp 2(1+N)G - 1]\,[1 + 2N + w + (k+1)/2] + N + 1$$

where

$N = \dfrac{\text{propagation time}}{\text{transmission time}}$

In a typical packet radio network, N is extremely small, $10^{-3}$ or less. The term can be safely ignored.

$w =$ time required to generate an acknowledgement

$k =$ packet retransmission protocol delay

### 2. Slotted ALOHA

Although the Pure or Basic ALOHA network comprised only useful deliverable information, it was considered too inefficient (throughput 18.4%) for many applications. This inefficiency created a lot of research into ways for achieving greater capacity while keeping the simplicity of a random broadcast system. One of the solutions was to establish a slotted channel (a channel with discrete time slots in which users may transmit their information). The so-called Slotted ALOHA broadcast network [Ref. 21] can considerably reduce the vulnerable period of Figure 8 when a packet of information is likely to create interference.

Slotted ALOHA divides the channel into organized, uniform slots whose size is equal to the transmission time of the packet. A central clock or other timing mechanism is used to synchronize all the users on the system. When a user has information to transmit, he or she must wait until the

beginning of the time slot before sending the traffic. Under this scheme, only packets which overlap completely will collide and be destroyed.

a. Capacity and Delay of the Slotted ALOHA Network

Calculating the throughput is fairly straightforward. The number of packets that are transmitted during a time slot is equal to the number that was generated during the previous time slot and which had to wait for transmission. The probability that no other packets were generated during the previous time frame is exp (-G). Stating it another way, exp (-G) is the probability that a packet being transmitted will be successful in reaching its destination because no other packets were generated to collide with it. Therefore, probability theory says that the probability an individual packet will suffer a collision is 1 - exp (-G). Finally, the throughput of a Slotted ALOHA channel is the channel load (G) times the probability that the packets are successful in reaching their destination:

$$S = G \exp(-G)$$

The throughput-offered traffic load relation for the Slotted ALOHA is shown in Figure 10. Similar to the Pure ALOHA broadcast network, the channel traffic in Slotted ALOHA increases quickly, reaching maximum capacity (G=1/2) at a useful throughput of 0.368. The channel utilization of

Slotted ALOHA can be twice that of the Pure ALOHA system. Maximum throughput is based on the assumption that each transmission contains a full packet. If, on the average, the packets were only half full, the actual throughput will be that of the Pure ALOHA since no other user can transmit during the empty portion of the Slotted time interval. [Ref. 19:p. 237]

Delay on a Slotted ALOHA broadcast channel is estimated in the same manner as Pure ALOHA. The only difference is that, on the average, each time a user is ready to make a transmission he or she has to wait one-half of a packet time until the beginning of the next slot interval before the packet can actually be transmitted. The delay equation is: [Ref. 20:p. 295]

$$\text{Delay} = [\exp(G) - 1]\,[\,1 + 2N + w + (k + 1)/2\,] + N/2 + 1/2$$

where N = propagation protocol delay
w = time to generate an acknowledgement at rcvr
k = retransmission protocol delay

Under heavy channel loading conditions the delay equations for both Pure and Slotted ALOHA confirm the instability of contention-based protocols. As the rate of new packets increases, so does the number of collisions. Both the number of collisions and the average delay grow exponentially with the offered load. Figure 11-a shows that delay increases exponentially with the offered load. Figure 11-b indicates that delay increases with throughput up to the

maximum possible throughput. Beyond that point, although the throughput declines because of the increased collisions, the delay continues to increase.

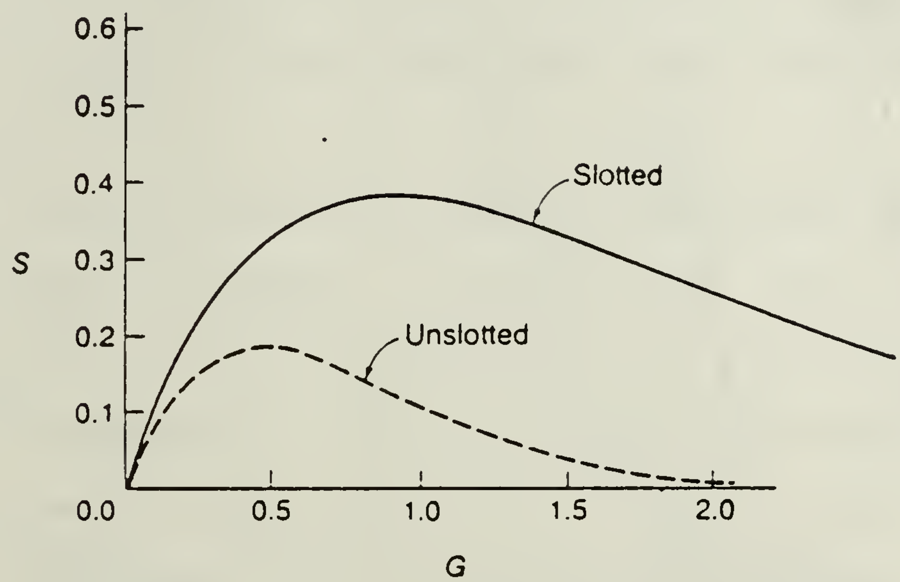
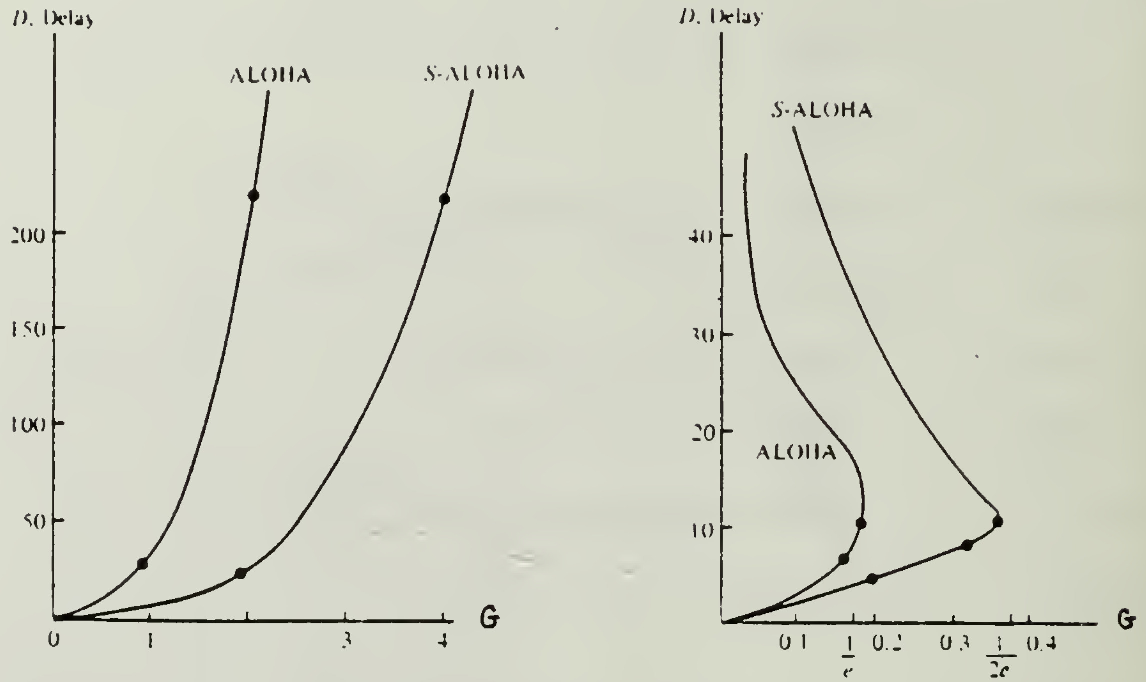



Figure 10. Plot of Channel Throughput Versus Channel Traffic for Slotted and Pure ALOHA

c. Disadvantages

Even though Slotted ALOHA has the capability of improving the throughput to twice the value of Pure ALOHA, two potential problem areas can limit the usefulness of the network. Proper clock synchronization is the whole key to the Slotted ALOHA network. The potential exists for the need of highly sophisticated user equipment, not only to synchronize the clocks but also to allow for the variation in actual distance between the users and the master clock. Secondly, a user is limited in the amount of data that can be

sent at any given time since the packet length and time slots are fixed.




(a) (b)

Figure 11. Delay as a Function of Channel Loading (G)

3. Slotted ALOHA with CAPTURE

It was assumed in the cases of Pure and Slotted ALOHA that whenever two or more packets overlapped, all were destroyed and required retransmission. If one of the radio signals happened to be strong enough to "capture" the receiver and block the other signals, the packet could be transmitted correctly and accurately. This situation could occur when one transmitter is closer to the receiver than the

others or when one transmitter uses more power. It is possible then to allow users with a need to transmit, based on some priority scheme, to increase their power output. This creates a higher probability of being received correctly even in the presence of interfering packets. Rosner [Ref. 19:pp. 238-240] has analyzed this type of situation and it is summarized below.

a. Capacity of Slotted ALOHA with CAPTURE Network

Rosner assumed for simplicity that, based on sufficient random fluctuations in received signal levels, for any pair of users there would be a one-half probability that one of the users would capture the receiver and transmit correctly. If three or more users transmit at the same time no one has power enough to capture the receiver and all packets are destroyed. Using a slightly modified version of the Slotted ALOHA throughput equation, Rosner concluded that a Slotted ALOHA channel with CAPTURE increased the channel capacity to 0.552, nearly a 50% increase over Slotted ALOHA. The throughput equation is:

$$S = G \exp(-G) \times (1 + G/2)$$

To analyze the probability of capture for different transmitter conditions, the denominator in the last term of the throughput equation can be changed. For example, when two packets collide and the probability that one user successfully completes the transmission is one-third, the probability that the other user completes the transmission is

one-third, and the probability that neither packet is received is one-third, then the last term becomes G/3. This assumes an equal probability distribution that each of the transmitter sites will capture the receiver. Figure 12 shows the effect of CAPTURE over Pure and Slotted ALOHA.

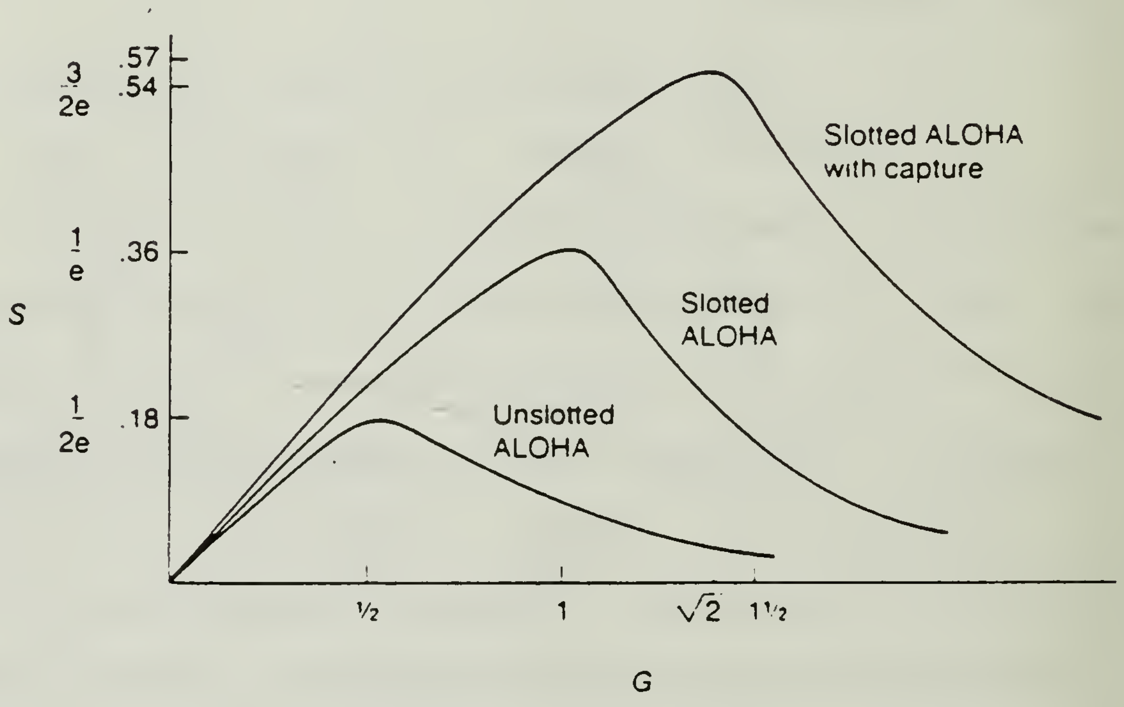



Figure 12. Plot of Throughput Versus Channel Traffic for Slotted, Pure, and Capture ALOHA Systems

## C. CARRIER SENSE MULTIPLE ACCESS

Terrestrial ALOHA broadcasting networks such as packet radio systems inherently have extremely short propagation delays. This feature allows the ALOHA channel utilization to be pushed far above the 1/e limit imposed by Slotted ALOHA.

When the propagation delay is short compared to the transmission of the information packet, a user can listen to the channel before sending traffic. This method of operation is called Carrier Sense Multiple Access (CSMA).

Networks in which the station-to-station propagation time is large compared to the data transmission time have many packet collisions. A significant block of time elapses between the time one user sends traffic and the time other users on the network know about it. During that time frame another user may transmit a packet thinking the channel was clear. The result is that both packets collide and are destroyed. In the reverse situation where the propagation time is very small compared to the packet time, every user on the network knows immediately when another user has sent traffic. A user wishing to send traffic can listen first to the channel and base his actions on whether the channel is busy or not.

F.A. Tobagi analyzed several of the CSMA protocols of which a few of his results are presented below. All of Tobagi's analyses are based on the following assumptions: [Ref. 16:p. 289]

(1) All packets are of constant length.

(2) There are no errors, except those caused by collisions.

(3) There is no capture effect.

(4) The random delay after a collision is uniformly distributed and large compared to the packet transmission time.

(5) Packet generation attempts (original calls plus re-transmissions) from a Poisson process with mean G packets per packet time.

(6) A station may not transmit and receive simultaneously.

(7) Each station can sense the transmissions of all other stations.

(8) The propagation delay is small compared to the packet transmission time, and identical for all stations.

(9) Sensing the state of the channel can be done instantaneously.

### 1. Nonpersistent CSMA Protocol

There are three general CSMA protocols to examine. The first protocol is called Nonpersistent CSMA. A user desiring to transmit listens to the channel and obeys the following rules [Ref. 22:p. 472]:

(1) If the channel is idle, transmit.

(2) If the channel is busy, wait a random delay period and repeat step 1.

If there are several stations that have traffic to pass, there is likely to be some wasted idle time following a prior transmission.

#### a. Throughput of a Nonpersistent CSMA Network

For the case of zero propagation delay, both the Pure and Slotted ALOHA versions of Nonpersistent CSMA give the same throughput as a function of demand:

$$S = G/(1 + G)$$

b. Delay Through a Nonpersistent CSMA Network

The calculation for Total Average Delay (TAD) through a Nonpersistent CSMA network follows a rigorous approach and only the final equation is presented here. For an in-depth view of the mathematics, the reader is directed to Kleinrock and Tobagi's research on CSMA modes and their throughput-delay characteristics [Ref. 23:pp. 1414-1415].

$$TAD = [ (G/S - 1) R ] + 1$$

where G = channel loading
S = channel throughput
R = total time required to transmit a call alert and call acknowledgement sequence, to include re-transmission delay protocol

2. <u>1-Persistent CSMA Protocol</u>

The second protocol, which avoids this idle-time is labeled 1-Persistent CSMA. Again, a user wishing to send a packet listens to the channel and obeys the following rules [Ref. 22:p. 472]:

(1) If the channel is quiet, transmit.

(2) If the channel is busy, continually sense the channel until it becomes idle, then transmit immediately.

(3) If there is a collision, wait a random period of time and then repeat step 1.

Although this protocol avoids the channel idle time, more collisions result. If two users become ready to transmit while another is in the process, both wait until the transmission has completed. Immediately upon hearing the end

of the present transmission, both users transmit their packets, thereby resulting in a collision. Even so this protocol is better than just using Pure or Slotted ALOHA because the users desist from interfering with the third user's packet.

a. Throughput of a 1-Persistent CSMA Network

Again, for the case of zero propagation time and valid for both Pure and Slotted ALOHA systems, the throughput is the following:

$$S = \frac{[G \exp(-G)]\,(1 + G)}{G + \exp(-G)}$$

b. Delay Through a 1-Persistent CSMA Network

Similar to the theory behind the Nonpersistent CSMA Total Average Delay (TAD) equation, TAD for a 1-Persistent CSMA network is also a complicated equation. The reader may refer to [Ref. 23] if desired for the complete calculations. The Total Average Delay equation is:

$$TAD = [\,(G/S - 1)\,(1 + 2a + \alpha + \delta + r)\,] + r + a + 1$$

where $G$ = channel loading
$S$ = channel throughput
$a$ = propagation delay
$\alpha$ = transmit time of call packet divided by the transmit time of the acknowledgement packet
$r$ = average delay a packet waits before transmitting after it sensed the channel was busy
$\delta$ = re-transmission delay protocol

### 3. P-Persistent CSMA Protocol

The third protocol applies to Slotted ALOHA and is called P-Persistent CSMA. This protocol attempts to reduce both the idle time seen in Nonpersistent CSMA and the number of collisions resulting from 1-Persistent CSMA. Any users having traffic to send listen to the channel and obey the following rules [Ref. 22:p. 472]:

(1) If the channel is idle, transmit using a probability P, and delay one time unit with probability q=(1-P). The time unit is typically equal to the maximum propagation delay.

(2) If the channel is busy, continually sense until the channel is idle and repeat step 1.

(3) If transmission is delayed one time unit, repeat step (1).

With P-Persistent CSMA, arguments arise over what value of P is best. The main problem to avoid is one of instability under heavy channel loading conditions. If N users have packets to send while a transmission is currently taking place, the expected number of users that will attempt to transmit when the channel becomes idle is NP. Multiple users will transmit and a collision will result. As soon as all these stations realize that they did not get through, they will be waiting to transmit again. These retransmissions, along with any new packet arrivals, further increases the probability of a collision. Within a short period of time, all users will be trying to send packets, causing continuous collisions, and therefore, throughput is

zero. The value NP must be less than one for the expected peaks of N. Otherwise, during the peak periods, 100 percent of the expected number of users (NP) will attempt to transmit when the channel becomes idle. As P is made smaller, users must wait longer to attempt a transmission but this reduces the number of collisions. At low channel loading, however, users will have unnecessarily long transmission delays.

a. Throughput of a P-Persistent CSMA Network

The analysis of the throughput of this protocol is very complicated. For a zero propagation delay assumption, the throughput is given as: [Ref. 16:p. 291]

$$S = \frac{[G \exp(-G)]\,(1 + PGX)}{G + \exp(-G)}$$

where

$$X = \sum_{K=0}^{\infty} \frac{(qG)^{K}}{(1 - q^{K+1})k!}$$

$$q = 1 - P$$

For all P > 0, the throughput drops to 0 as G approaches infinity. For P approaching 0, the asymptotic throughput is 1.0 but the delay becomes infinite. Figure 13 shows the throughput versus offered traffic for all three protocols, as well as Pure and Slotted ALOHA. It is clear that vast improvements can be made using the techniques of Carrier Sense Multiple Access.

b. Delay Through a P-Persistent CSMA Network

The Total Average Delay (TAD) calculation in a P-Persistent Network is also very complicated and the reader is

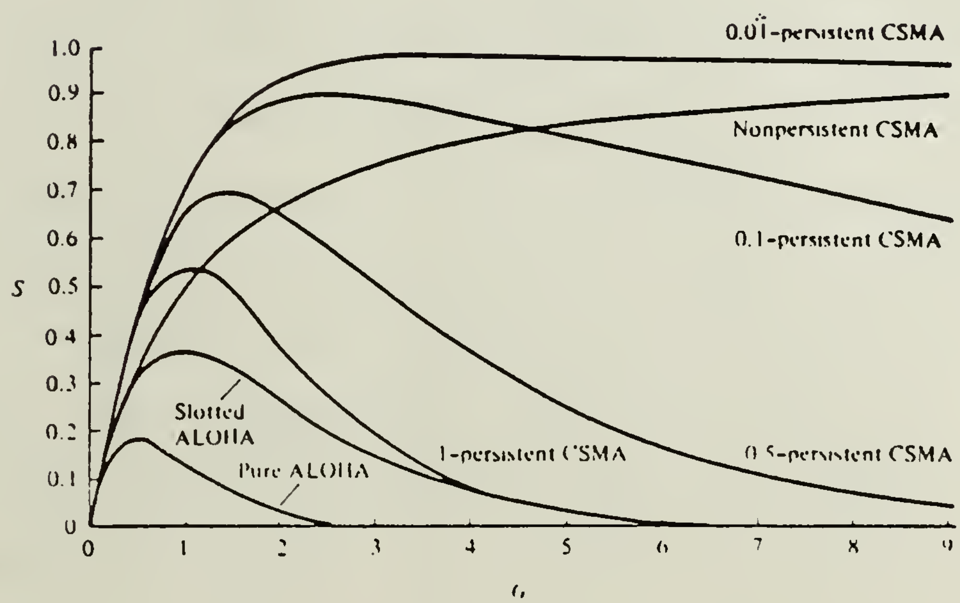



Figure 13. Throughput of Various Random Access Calling Systems with Propagation Delay = 0

directed to [Ref. 23:p. 1415] for an in-depth analysis. The delay as presented by Kleinrock and Tobagi's paper is:

$$TAD = (G/S - 1)\,[\,1 + 2a + \delta + r\,] + 1 + a + r$$

where G = channel load
S = channel throughput
a = propagation delay
$\delta$ = retransmission delay protocol
r = initial delay due based on the probability p

Now that this thesis has discussed various random access calling methods available for the transmission of a DSC call sequence, the author will present the current mathematical model advocated by the CCIR. This model is developed around the 1-Persistent CSMA random access calling system.

# IV. CURRENT VHF-FM DIGITAL SELECTIVE CALLING MODEL

## A. INTRODUCTION

A study group of the CCIR, Interim Working Party (IWP) 8/10, met in October 1984 to discuss, among other agenda items, the VHF channel requirements for a digital selective calling system. A DSC VHF model submitted to the study group postulated a worst-case situation based on the maximum number of VHF working channels allowed by Appendix 18 to the Radio Regulations and the maximum channel loading capacity of those channels. Based on those calculations, which are presented below, it was recommended that all VHF DSC calling, commercial and distress, should be made on a single frequency VHF channel.

There are two types of commercial DSC calls, a navigational call and a general call. Navigational calling is used to transmit information regarding a vessel's position and intended movement. A navigational DSC call requires a DSC call alert sequence from the sending station and a DSC call acknowledgement sequence from the receiving station. If an acknowledgement sequence is not received, the sending station re-transmits the DSC call alert sequence. The reception of a DSC call acknowledgement sequence terminates the communications on the calling channel. Further

communications, if necessary, are carried out on a "working" channel designated in the DSC call alert sequence.

A VHF-FM transmission that is not a distress or navigational call is defined as a general call. A general DSC call also requires a DSC call alert sequence and a DSC call acknowledgement sequence. Once the call acknowledgement sequence is received, communications are either terminated or shifted to a "working" channel.

## B. TRAFFIC ANALYSIS

In order to calculate the required number of VHF calling channels, the predicted channel loading on those channels was needed. Since actual VHF channel loading conditions were not known, the developers of the mathematical model submitted to Interim Working Party 8/10, which will be referred to as the IWP model, determined that the maximum possible signalling intensity at VHF would occur in densely populated areas. Channel assignment schemes will preclude interference on working channels except under severe ducting conditions. Therefore, the maximum number of working channels for general VHF calling within the possible range of a calling ship is 28, according to Appendix 18 of the Radio Regulations.

In addition to general calls, a VHF DSC channel could also be used for navigational communications. These communications are currently transmitted on the single-frequency channels of which Appendix 18 of the Radio

Regulations allots 19 channels (excluding channel 70 which is currently reserved for distress and safety calling only) [Ref. 11:p. 7].

Statistics from the Federal Republic of Germany and from Denmark indicate that a working channel has a maximum capacity of 0.8 Erlangs, and that the average duration of a commercial communication was 5 minutes [Ref. 4:p. 18]. These channel capacity and call duration figures were given without reference to how they were calculated. The VHF traffic analysis figures used in the IWP model are listed in Table 2.

TABLE 2

VHF TRAFFIC ANALYSIS

| | |
|---|---|
| Maximum working channels | 28 |
| Maximum navigational channels | 19 |
| Maximum channel loading in Erlangs | 0.8 |
| Average call duration in minutes | 5 |

## C. OTHER FACTORS INFLUENCING THE NUMBER OF CALLING CHANNELS

There are other factors which can influence the number of calling channels required in the proposed VHF DSC system. CCIR Report 493-2 and CCIR Interim Working Party 8/10 report of November 1984 list several of these factors which are presented below.

### 1. Duration of DSC Call Sequences

There are three distinct types of DSC sequences: 1) commercial call alert, 2) commercial call acknowledgement, and 3) distress call alert [Ref. 14:p. 8]. The first two DSC call alert sequences have a duration of 0.57 seconds each while the distress DSC call alert sequence will be 0.38 seconds in length.

Channel loading characteristics are partially calculated using the duration of a DSC sequence. Since the Intergovernmental Maritime Organization (IMO) has placed the maximum permitted loading of a random access calling channel at 0.1 Erlang [Ref. 2:p. 2], an increase in any of the DSC call durations will adversely impact on the loading of the channel, possibly increasing the number of channels required. Channel loading is calculated using the number of calls arriving per hour and the duration of a single call. For the channel loading due to DSC calling, each individual call is multiplied by the respective number of DSC sequences for that call. For example, a commercial DSC call actually consists of 4 DSC sequences: 2 call alert DSC sequences and 2 call acknowledgement DSC sequences. A distress DSC call consists of 10 DSC sequences as explained below. The Erlang equation is given as:

$$\text{Erlangs} = \frac{(\text{calls}) \times (\text{call duration}) \times (\text{\# of sequences})}{3600\ (\text{seconds/hour})}$$

### 2. Number and Duration of VHF DSC Sequences

The CCIR has recommended that for a commercial call to be successful, it must consist of a DSC call alert sequence from the sending station and a DSC call acknowledgement sequence from the receiving station back to the sending station. Because of the time-diversification requirement set forth by CCIR Recommendation 908, each DSC sequence will actually be transmitted twice. For a commercial call this translates into four DSC sequences: two DSC sequences for the sender's call plus two DSC sequences for the acknowledgement call. According to the IWP VHF-FM DSC model, for a commercial call, a one-way DSC call sequence has a duration of 0.57 seconds, and the total duration of a successful call (call alert plus acknowledgement) is 1.14 seconds. The IWP calculation for the number of DSC sequences per successful call was [Ref. 4:p. 18] :

1 Call x 2 DSC seq/call = 2 DSC sequences

2 DSC seq x 0.57 sec/seq = 1.14 seconds

A single DSC distress call, as defined by the CCIR, will actually consist of four repetitions of the same call. An analogy to the present voice VHF-FM system is that the unit in distress transmits its complete distress call five times, one right after the other. Returning to the DSC model, each distress call is repeated five times, and each

DSC sequence is transmitted twice for time-diversification. This results in the ultimate transmission of 10 DSC sequences.

Distress call x 5 repeats/call x 2 DSC seq/call = 10 DSC seq

Each distress call DSC sequence is 0.38 seconds in duration and the total transmission time for a distress call is 3.8 seconds. No acknowledgement sequence is required for a distress call.

Channel loading calculations are determined in part by the length of a DSC call. Since a successful DSC call sequence consists of several individual call sequences, a higher traffic loading will result. This may increase the number of required DSC calling channels.

3. Use of Scanning Devices

The dot-pattern is used in DSC calling for synchronization purposes. If more than one DSC channel is being used for calling, a scanning device is required to sample each channel for traffic. The scanner will halt at a particular channel only if the dot-pattern is recognized. Since some time is required to determine if a call is destined for another station, there is a non-zero probability that some calls will be lost due to scanning. The use of scanning devices will limit the number of calling channels.

At present only MF and HF DSC calls will utilize the dot-pattern technique.

4. <u>Position of Coast and Ship Stations</u>

In the calculation of the number of calling channels, it was assumed that the position of the called station was known. This permits the selection of the optimum frequency bands, the correct channel in the selected frequency band, and the optimum time to call the station. This pertains to all DSC calling but may be of more importance in VHF calls due to its limited calling range. Out of range calls will result in retransmissions, ultimately increasing the traffic loading on the channel.

Ship stations have an anomaly in communications in that the ship-to-ship communication range is usually less than the range between a ship and a coast station. This situation creates the problem that not every call in progress on a random access calling channel is necessarily heard by all possible interferers. Two ship stations within the same coast station coverage area may possibly be out of range with each other. Since both ships think the channel is clear, they each access the channel to send traffic. The IWP model of a VHF DSC system assumes that a particular ship will only be able to hear approximately 30% of the other ships in the area. The end result is that the coast station may have interference from 70% of the total ship station signalling occurring. [Ref. 4:p. 19]

## D. CCIR INTERIM WORKING PARTY 8/10 VHF DSC SYSTEM MODEL

The IWP model determined the worst-case required number of VHF DSC calling channels, given a projected channel loading condition. The channel loading (offered load) calculation is made in seconds, with the total number of call-seconds divided by 3600 (number of seconds in an hour) to arrive at the number of Erlangs over the busy hour calling period. The model of the VHF DSC system presented before the Interim Working Party 8/10 group, with a large number of independent calling stations, closely approximates a random access calling system such as those listed in Chapter III. As such, the IWP model uses the Poisson process for the generation of calls.

$$P(t) = \frac{(\lambda t)^{k} \exp(-\lambda t)}{k!} \qquad k > 0 , t > 0$$

where
$\lambda$ = mean call arrival rate
t = mean duration of the call
P (t) = probability of k calls arriving during time t

The first calculation was to determine the projected channel loading on VHF. Referring to Table 2, the maximum number of working channels available is 28, each having a maximum capacity of 0.8 Erlang. The call duration is 5 minutes in length. The maximum number of commercial communications per hour from the coast stations which

simultaneously may receive the same DSC call is calculated as:

$$\frac{28 \text{ channels} \times 0.8 \text{ Erlang} \times 60 \text{ min/hour}}{5 \text{ min/call}} = 269 \text{ calls/hour}$$

Two DSC sequences (call alert plus acknowledgement) are required to set up a general commercial communication on a working channel. This will require:

$$269 \text{ calls/hr} \times 2 \text{ DSC seq/call} = 538 \text{ DSC seq/hr}$$

The duration of a general DSC sequence is 0.57 seconds which corresponds to:

$$\frac{538 \text{ DSC seq/hour} \times 0.57 \text{ seconds/DSC seq}}{3600 \text{ seconds/hour}} = 0.085 \text{ Erlang}$$

This Erlang figure represents the projected maximum single channel loading during the busy hour from general DSC calling. It corresponds to the hypothetical worst-case scenario where only one coast station would receive all the DSC calls necessary for establishing communications on the total number of working channels allocated in Appendix 18 of the Radio Regulations.

In addition to calls for general commercial correspondence, the calling channel may be used for calls

establishing navigational communications, e.g. communications on the single-frequency channels. Again, assuming a worst-case situation, the calling channel must handle the communications carried by the total number of single-frequency channels of Appendix 18. This number, less channel 70 which is assigned for distress and safety calls only, is 19. Channel 70 was designated exclusively for simplex CCIR DSC distress and safety purposes by the Final Acts of the WARC 1983 conference. [Ref. 11:p. 7]

The maximum number of DSC sequences per hour due to navigational calls, assuming the same call set-up, duration, and channel efficiency as a general commercial call, will be:

$$\frac{19 \text{ chnls} \times 0.8 \text{ Erlg} \times 2 \text{ seq/call} \times 60 \text{ min/hr}}{5 \text{ min/call}} = 366 \text{ seq/hr}$$

$$\frac{366 \text{ DSC seq/hr} \times 0.57 \text{ seconds/seq}}{3600 \text{ seconds/hour}} = 0.058 \text{ Erlang}$$

The total load on the calling channel for general and navigational calls is:

538 DSC sequences + 366 DSC sequences = 904 DSC sequences

$$\frac{904 \text{ DSC seq/hr} \times 0.57 \text{ seconds/seq}}{3600 \text{ seconds/hour}} = 0.143 \text{ Erlang}$$

Using the concept of a Basic ALOHA random access channel and the Poisson process for call arrivals, the probability that no new calls are generated while another call is in progress is:

$$P(t) = \frac{(0.143)^{0} \exp(-0.143)}{0!}$$

$$= 0.867$$

The probability that a new call is made while another is in progress is, therefore:

$$P1 = 1 - 0.867 = 0.133$$

Recalling from Chapter III and Figure 8, a call will suffer a collision if any other call is generated within one call length of its start. The probability that a DSC call is destroyed by another call because of a collision is:

$$P2 = 1 - \exp(-2 \times 0.143) = 0.249$$

The developers of the IWP model consider the probability P2 to be too high [Ref. 4:p. 19]. Shifting the attention to the principles of Slotted 1-Persistent CSMA, the IWP model calculates the probability of a call colliding with another

call. This probability is equal to the probability that 2 calls are generated while one call is in progress:

$$P3 = (P1)^2 = 0.018$$

Assuming that a ship station can only hear approximately 30% of the other ships in the area, this results in interference at the coastal station from 70% of the total ship station traffic. When the DSC calling channel is used for general calling only (projected 538 call sequences per hour maximum), disciplined access occurs for 350 DSC call sequences (269 coast station call sequences plus 30% of the ship station call sequences) while 188 DSC call sequences enter the communications system randomly.

The probability that a general call is generated while another is in progress, resulting in a collision is:

$$P4 = 1 - \exp( -538 \times 0.57 ) = 0.082$$

The probability that the general call will collide with a randomly entered commercial call is:

$$P5 = 1 - \exp( -188 \times 0.57 ) = 0.029$$

The total probability of losing a randomly entered general commercial call is then:

$$P6 = P4 + ( 1 - P4 ) P5 = 0.109$$

If the DSC calling channel is also used for navigational call, 70% of the navigational calls (256 DSC sequences) enter the system randomly since they originate from ship stations or low range land-based stations for port operations, pilot stations, etc.

The combination of 188 general DSC calls and 256 navigational calls (444 DSC sequences) access the DSC calling channel randomly. The probability that a randomly entered commercial call (general and navigational) will collide with a commercial call in progress is:

$$P7 = 1 - \exp ( -904 \times 0.57 ) = 0.133$$

The probability that this random commercial call collides with another commercial call entered randomly is:

$$P8 = 1 - \exp ( -444 \times 0.57 ) = 0.068$$

Finally, for a DSC channel containing only commercial calls (general and navigational) ,the total probability of losing a randomly entered commercial call is:

$$P9 = P7 + ( 1 - P7 ) P8 = 0.192$$

The IWP model considers this probability to be within reason. The above calculations assume that only one coast station would be receiving DSC calls for all coast station working channels and all navigational channels in the Radio Regulations. In practice, the maximum number of coast stations in the Danish/Swedish waters which simultaneously can receive the same DSC call is 9, with a total of 17 working channels at present [Ref. 4:p. 21]. The traffic statistics for these waters show a stagnation in the traffic so it is unlikely that the channel loading will ever exceed that corresponding to 20 working channels ( 0.06 Erlang). Therefore, a 50% margin is available to cope with conditions of extraordinary ducting or call congestion.

One other assumption was that the navigational DSC calls will have the same duration as the commercial DSC calls. The duration of a navigational call will only be 75% of a commercial call duration. This fact will reduce the actual channel loading.

It was shown that a single VHF DSC channel could carry general and navigational commercial communications traffic

with a 19.2% probability of losing a randomly entered commercial call. The IWP communications model concluded with a discussion on the effect of distress calling if there was a common VHF channel for DSC distress and commercial calls.

The probability that a commercial call is in progress when a distress call is initiated is:

$$P10 = 1 - \exp ( -904 \times 0.57 ) = 0.133$$

The probability of this random commercial call colliding with another commercial call entering the system randomly is:

$$P11 = 1 - \exp ( -444 \times 0.57 ) = 0.068$$

Therefore, the probability that a distress call will collide with a commercial call is:

$$P12 = P10 + ( 1 - P10 ) P11 = 0.192$$

Since a distress DSC sequence consists of 5 individual calls, the probability of collision destroying all 5 calls by a commercial call is:

$$P13 = ( P12 )^{5} = 0.000262 \text{ or } 1/3815$$

If only distress calls are allowed on the DSC channel, the collision probability between any 2 distress calls within one hour is:

$$P14 = 1 - \exp(-2 \times 2 \times 0.38) = 0.000422$$

On a VHF DSC calling channel where distress and commercial calling are both present, the additional or marginal loss of distress call attempts due to commercial calling will be:

$$P15 = P14 + (1 - P14)\, P13 - P14$$
$$\doteq 0.000262$$

When using a single channel for both distress and commercial calls the combined effect of the maximum possible commercial traffic density can not exceed the risk that one distress call attempt may collide with another one. [Ref. 4:p. 22]

## E. SCANNING WITH A 1-SECOND DOT PATTERN

If a dedicated channel is used for distress calls, the use of a scanning device may be necessary. The scanning

process will produce lost calls and the dot-pattern will increase the channel loading considerably.

The channel loading of commercial calls alone would be:

$$\frac{904 \text{ DSC seq} \times 1.57 \text{ seconds/DSC seq}}{3600 \text{ seconds/hour}} = 0.394 \text{ Erlang}$$

This figure clearly exceeds the IMO standard of 0.1 Erlang for the maximum channel loading permissible on a random access channel.

## F. INTERIM WORKING PARTY 8/10 DSC MODEL CONCLUSIONS

The conclusion drafted by the IWP model developers was to recommend that all DSC calling be made on a single-frequency VHF channel. This was based on the insignificant difference between the probability of losing a single distress call attempt on a separate calling channel and that using a combined distress/commercial calling channel.

The author of this thesis feels that the current model does not consider all the criteria relevant to a combined distress and commercial calling channel. Although the current model has taken the probability of losing a single distress call attempt (probability of delay) into account, other grade of service aspects such as the probability of answering a distress call within a certain time frame and the actual time delay in the transmission of a call sequence need to be considered. Therefore, the author has developed a

model which includes these grade of service parameters. This model is the subject of the next chapter.

# V. PROPOSED VHF-FM DIGITAL SELECTIVE CALLING MODEL

In order to gain an understanding of the real-world behavior of a VHF-FM Digital Selective Calling system, a mathematical model can be effectively used to analyze how various situations affect that behavior. As an example, when the channel loading increases on the calling channel, the analyst may wish to know what effect that increase has on the probability of receiving and acknowledging a single call. This chapter discusses general modeling requirements for the VHF-FM DSC system, specific parameters to be used in the model, and applies the model to the random access calling systems of Chapter III.

## A. GENERAL MODELING REQUIREMENTS

Several aspects of the VHF-FM DSC system need to be clarified so that the development and application of the math model will be evident. The first aspect to be considered concerns the generation and interarrival of calls in the system. The Poisson process, used frequently in telecommunication network theory, is used in this model to describe the generation and interarrival of calls at a VHF reception facility. The Poisson process is based on the assumption that there is an infinite population of statistically unrelated calls and/or callers. The VHF-FM

Digital Selective Calling system fits into this category because, although not a true infinite set, there is a sufficiently large base of potential users in the maritime industry, including recreational boaters, to make this assumption. The assumption also includes that each user is statistically independent of the other users. It has been shown that for a Poisson arrival process, the time between arrivals (interarrival time) is exponentially distributed [Ref. 24:p. 65].

The second aspect of a VHF-FM DSC system pertains to the types of calls, including their format and duration characteristics, that are going to be placed on the system. The new DSC system will have to accommodate the same types of calls currently present on the voice VHF-FM channels. These are the distress and safety calls, and the commercial calls, which include both general and navigational calls.

The final aspects of the system to consider are the parameters to be used for the model. These include but are not limited to the specific levels of channel loading, probabilities of a call being blocked, delays through the system, and reliability.

## B. SPECIFICATIONS OF THE PROPOSED MODEL

This section describes the assumptions used in the proposed model for the VHF-FM DSC system. Following general telecommunication network theory, the Poisson process will be

used to calculate the maritime traffic call arrivals and interarrival times.

### 1. Format and Duration of Call Sequences

A single DSC channel is proposed to accommodate both distress and commercial (general and navigational) calling. Except for non-routine calls, safety calling will be transmitted on a separate channel [Ref. 15:p. 3].

A calling channel is used primarily for the transmission of a short message to indicate that a calling party desires to transmit further information on another channel called a "working" channel. In the present voice VHF-FM calling and distress system, a call contains a call alert transmission from the sending station and a call acknowledgement transmission from the receiving station. Once those transmissions have taken place, the two stations switch to the desired "working" channel to complete their transmissions. In the proposed VHF-FM DSC system, the term DSC sequence is used to indicate a one-way transmission such as a single call alert message or a single call acknowledgement message.

A successful commercial DSC call consists of one DSC call alert sequence from the sending station plus one DSC call acknowledgement sequence from the receiving station. CCIR Report 908 specifies that each sequence will be sent twice for time-diversification. Therefore, each commercial call generated will require four DSC sequences: two call

alert sequences and two call acknowledgement sequences. The duration of each commercial DSC call sequence is 0.57 seconds.

A distress DSC call will actually consist of ten DSC sequences. The original distress call alert DSC sequence will be re-transmitted four times, one right after the other, making a total of five DSC sequences. Because of time-diversification, each of the five DSC sequences will be transmitted twice, accounting for the distress call total of ten (10) DSC sequences. The duration of each distress DSC call alert sequence is 0.38 seconds. No acknowledgement is required on a distress call. A distress call is successful if further communications are established between the station in distress and another station on the "working" channel designated in the distress DSC call alert sequence. If communications are not established on the "working" channel, the station sending the distress shifts back to the DSC calling and distress channel and re-transmits the complete distress call (10 sequences), after waiting the required period of time designated by the re-transmission delay protocol.

The re-transmission delay protocol for all calls is assumed to be forty-five (45) seconds in duration.

2. Channel Loading

The projected maximum channel loading due to general calls on VHF is calculated from the sum total of all general calling channels presently allocated (28 working channels). Using 0.8 Erlang as the maximum channel loading capacity on a single channel [Ref. 4:p. 18] and 5 minutes as the average call holding time for a voice call [Ref. 19:p. 20], the maximum number of general calls expected is 269 calls per hour. This figure represents original calls plus those calls re-transmitted due to collisions.

$$\frac{28 \text{ channels} \times 0.8 \text{ Erlang} \times 60 \text{ min/hr}}{5 \text{ min/call}} = 269 \text{ calls/hr}$$

Since 4 DSC sequences are required for a successful general call, the number of DSC sequences is:

$$269 \text{ calls/hr} \times 4 \text{ DSC sequences/call} = 1076 \text{ DSC seq/hr}$$

The duration of each general call DSC sequence is 0.57 seconds. The channel loading due to general calling is calculated as follows:

$$\frac{1076 \text{ DSC seq/hr} \times 0.57 \text{ sec/DSC seq}}{3600 \text{ sec/hr}} = 0.170 \text{ Erlang}$$

The projected maximum channel loading due to navigational calls on VHF is calculated from the sum total of all the single-frequency channels presently allocated (19 excluding channel 70 which is assigned to distress traffic

only). Using 0.8 Erlang as the maximum single channel loading condition and 3.75 minutes as the duration of a navigational call, the projected maximum number of navigational calls is 244 calls per hour. The developers of the IWP model chose to use 5 minutes as the duration of a navigational call, even though they stated that the duration of a navigational call was 75 percent (75%) of that of a general call. The actual load on a single-channel calling system will increase, not decrease as suggested by the IWP model developers, if the navigational call duration is in fact 3.75 minutes. This can be seen in the equation below by varying the duration of the navigational call (denominator) between 5 minutes and 3.75 minutes. At 5 minutes the number of calls on the 19 channels is 182 calls. Two DSC sequences per navigational call brings the total number of DSC sequences on the channels to 364 sequences, which translates into 0.058 Erlangs. When 3.75 minutes is used as the navigational call duration, the number of calls on the channels is 244, which translates into 0.077 Erlangs. In this light, the proposed model will use 3.75 minutes in order to obtain the worst-case channel loading conditions.

$$\frac{19 \text{ channels} \times 0.8 \text{ Erlang} \times 60 \text{ min/hr}}{3.75 \text{ min/call}} = 244 \text{ calls}$$

Since each navigational DSC alert sequence is assumed to have a corresponding DSC acknowledgement sequence, the

total number of DSC sequences per hour is calculated as:

244 calls x 4 DSC sequences/call = 976 DSC seq/hr

The duration of each navigational DSC sequence is 0.57 seconds, the same as a general call DSC sequence. The channel loading due to navigational calling is, therefore:

$$\frac{976 \text{ DSC seq} \times 0.57 \text{ sec/DSC seq}}{3600 \text{ sec/hr}} = 0.155 \text{ Erlang}$$

The projected channel loading due to distress calling assumes that distress traffic constitutes 1 percent (0.01) of all calling on the channel. There is no information available on the exact percentage of total calls that make up distress calls so the author will use 1 percent as a base line figure for the calculations presented below. Later in this chapter, tables will be formulated showing distress percentage of traffic ranging from 1 to 10 percent of total calls and its effect on the different random access systems. Assuming the average holding time for a voice distress call is the same as it is for a general call (5 minutes), the total number of distress calls per hour is calculated as:

269 general calls + 244 navigational calls = 513 total calls

513 commercial calls x 0.01 = 6 distress calls/hr

Each distress call will actually generate 10 distress DSC sequence transmissions as explained in section B.1. of

this chapter. The resultant number of DSC sequences per hour due to 1% distress calling is 60.

6 distress calls/hr x 10 DSC seq/distress call = 60 seq/hr

Each distress call DSC sequence is 0.38 seconds in duration [Ref. 4:p. 21]. The channel loading due to 1% distress calling is:

$$\frac{60 \text{ DSC seq/hr} \times 0.38 \text{ sec/sequence}}{3600 \text{ sec/hr}} = 0.006 \text{ Erlang}$$

The worst-case projected channel loading due to general calling, navigational calling, and 1% distress calling is 0.331 Erlang. This is obtained by summing the Erlang loading figures for each type of call.

0.170 (gen) + 0.155 (nav) + 0.006 (distress) = 0.331 Erlang

3. Grade of Service

The grade of service is defined as the probability of finding the VHF DSC system busy. Grade of service is the central design element in telecommunication traffic engineering as it involves the ability of the system to interconnect callers, and determines the speed with which the interconnection is made. The grade of service can be designated in various ways, some of which are the listed in

Table 3. The probability of a call being delayed longer than a specified time is especially important when a single channel is used for both calling and distress traffic. The

TABLE 3

GRADE OF SERVICE PARAMETERS

1. Probability of delay
2. Average delay of all calls
3. Probability of delay exceeding a specified amount of time
4. Channel throughput

probability of a successful distress call attempt within time t, for t ranging from 1 to 5 minutes, will be another one of the grade of service parameters used. The geometric distribution is used to determine this probability because the interest is in determining the probability that the first success will occur on any given trial. In this case the first success occurs when any one of the 10 DSC distress call alert sequences from a distress call arrives at the receiver. A trial, for this model, is the act of sending the 10 DSC sequences. The geometric distribution gives such a probability. The other grade of service parameters listed in Table 3 will also be calculated for the random access calling systems of Chapter III.

## C. APPLICATION OF THE PROPOSED MODEL

The grade of service parameters listed in Table 3 will be calculated in this section using the proposed VHF-FM Digital Selective Calling System model. The full set of calculations shown are based on the Basic Aloha Random Access Calling System, and use 0.1 Erlang as the channel loading factor (G) and 0.01 (1%) as the percentage of total calls that comprise distress calls. The tabulations for the remaining Basic Aloha calculations, as well as the other random access calling systems of Slotted Aloha, Slotted Aloha With Capture, Nonpersistent CSMA, and 1-Persistent CSMA, are listed in Tables 4a through Table 6j for ease of reading. Since Basic and Slotted CSMA throughput calculations are identical for both Nonpersistent and 1-Persistent CSMA, respectively, only one matrix for each calling system is tabulated. P-Persistent CSMA throughput and delay curves fall between those of the other CSMA calling systems (refer to Figure 13 of Chapter III) and therefore will not be included. The computer program used calculated precision to seven significant digits.

The Total Channel Load (G) figure is used to calculate the random access calling system Throughput (S) and the Total Average Delay (TAD) expected for a single DSC sequence.

$$S = (0.1) \times \exp(-2 \times 0.1) = 0.082$$

$$TAD = [[\exp(2 \times 0.1) - 1] \times [1 + (79 + 1)/2]] + 1$$

$= 10.08$ seconds

The Probability of Delay (PC1) for any one DSC sequence is calculated as the probability of collision due to the channel loading. PS1 is the probability of success for a DSC sequence to reach the receiver. The probability that a DSC sequence will not reach the receiver is PC1.

$PS1 = \text{Throughput} / \text{Load}$

$= 0.082 / 0.1 = 0.819$

$PC1 = 1 - PS1 = 0.181$

The probability of delay for a complete distress call attempt is obtained using the probability of collision for any one DSC sequence. Since a distress call attempt consists of ten DSC sequences, the probability that all ten sequences are destroyed (PC5) by colliding with another DSC sequence is:

$PC5 = ( PC1 ) = (0.181) = 0.0000000383$

$PS5 = 1 - PC5 = 0.9999999617$

To calculate the probability that at least one of the distress call alert DSC sequences will be successful within a certain time frame, the transmission time for the complete distress call attempt, including the re-transmission protocol

delay, is required. The duration of each distress DSC call alert sequence is 0.38 seconds. Each distress call consists of ten DSC alert sequences so the total time to transmit the DSC sequences is 3.8 seconds. The re-transmission delay protocol assumed is 45 seconds. Therefore, an unsuccessful distress call attempt requires 48.8 seconds to elapse before it will be re-transmitted. For each of the grade of service times desired, ( 1 to 5 minutes), the total time required for each unsuccessful distress call attempt is divided into that time (in seconds). For example, if the probability of success for a distress call to be completed within 1 minute is desired, divide 60 seconds by 48.8 seconds. By rounding down to the nearest whole number, this will give the maximum number of complete distress calls that can be made in that time frame. In this case only one call can be made, since only whole distress calls can be made. The geometric probability distribution is now used to determine the probability that the first success will occur on or before any given trial.

Geometric Probability

$$F(x) = \sum_{1}^{x} p\,(1-p)^{x-1} \quad \text{for } x = 1,2,3,4,\ldots\ldots$$

where p = probability of success
x = number of complete distress calls within the desired time frame

For the proposed model calculations, the probability of success for a complete distress call transmission was

determined above as PS5. The geometric distribution results in the following probability of success for one distress DSC sequence to be received correctly:

$$F(x) = (.9999999617) \times (1 - 0.9999999617) = 0.9999999617$$

Since only one complete distress call could be made within the desired time frame, this geometric probability is also the probability that the distress call will be successfully received within that time frame.

Tables 4a through 6j present the Probability of Delay (PC1) for any one DSC sequence, the Total Average Delay (TAD) in seconds, the Throughput (S), and the Probability of a Successful Distress Call Attempt within a certain time frame, $[P(T \leqslant t)]$. The calculations are obtained by varying the channel loading from 0.1 to 0.5 Erlang, varying the distress percentage of total calls from 1 percent (1%) to 10 percent (10%), and varying the time to complete a successful distress call from 1 to 5 minutes.

The chapter concludes, following the tables, with additional equations designed to calculate the marginal loss of distress call attempts due to commercial calling. These are presented for comparison purposes between the author's model and the IWP model shown in Chapter IV.

TABLE 4a

BASIC ALOHA

| 1% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.181 | 0.330 | 0.451 |
| Average Delay (TAD) | 10.08 | 21.16 | 34.71 |
| Throughput (S) | 0.082 | 0.134 | 0.165 |
| $P(t\leq 1)$ | 0.9999999 | 0.9999849 | 0.9996504 |
| $P(t\leq 2)$ | 0.9999999 | 0.9999999 | 0.9999998 |
| $P(t\leq 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 4b

BASIC ALOHA

| 1% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.484 | 0.551 | 0.632 |
| Average Delay (TAD) | 39.48 | 51.25 | 71.45 |
| Throughput (S) | 0.171 | 0.180 | 0.184 |
| $P(t\leq 1)$ | 0.9992920 | 0.9974360 | 0.9898141 |
| $P(t\leq 2)$ | 0.9999995 | 0.9999934 | 0.9998962 |
| $P(t\leq 3)$ | 0.9999999 | 0.9999999 | 0.9999989 |
| $P(t\leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 4c

SLOTTED ALOHA

| 1% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.095 | 0.181 | 0.259 |
| Average Delay (TAD) | 4.31 | 9.08 | 14.34 |
| Throughput (S) | 0.090 | 0.164 | 0.222 |
| $P(t\leq 1)$ | 0.9999999 | 0.9999999 | 0.9999987 |
| $P(t\leq 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 4d

SLOTTED ALOHA

| 1% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.282 | 0.330 | 0.393 |
| Average Delay (TAD) | 16.09 | 20.16 | 26.60 |
| Throughput (S) | 0.238 | 0.268 | 0.303 |
| $P(t\leq 1)$ | 0.9999969 | 0.9999849 | 0.9999111 |
| $P(t\leq 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 4e

SLOTTED ALOHA WITH CAPTURE

| 1% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.050 | 0.099 | 0.148 |
| Average Delay (TAD) | UNKNOWN | UNKNOWN | UNKNOWN |
| Throughput (S) | 0.095 | 0.180 | 0.255 |
| P(t≤1) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤2) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤3) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤4) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤5) | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 4f

SLOTTED ALOHA WITH CAPTURE

| 1% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.163 | 0.196 | 0.242 |
| Average Delay (TAD) | UNKNOWN | UNKNOWN | UNKNOWN |
| Throughput (S) | 0.277 | 0.322 | 0.379 |
| P(t≤1) | 0.9999999 | 0.9999999 | 0.9999993 |
| P(t≤2) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤3) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤4) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤5) | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 4g

CSMA NONPERSISTENT

| 1% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.091 | 0.167 | 0.231 |
| Average Delay (TAD) | 8.10 | 16.20 | 24.30 |
| Throughput (S) | 0.091 | 0.167 | 0.231 |
| $P(t \leq 1)$ | 0.9999999 | 0.9999999 | 0.9999996 |
| $P(t \leq 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 4h

CSMA NONPERSISTENT

| 1% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.249 | 0.286 | 0.333 |
| Average Delay (TAD) | 26.81 | 32.40 | 40.50 |
| Throughput (S) | 0.249 | 0.286 | 0.333 |
| $P(t \leq 1)$ | 0.9999991 | 0.9999964 | 0.9999831 |
| $P(t \leq 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 4i

CSMA 1-PERSISTENT

| 1% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.009 | 0.036 | 0.075 |
| Average Delay (TAD) | 0.77 | 3.00 | 6.54 |
| Throughput (S) | 0.099 | 0.193 | 0.278 |
| $P(t \le 1)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 4j

CSMA 1-PERSISTENT

| 1% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.089 | 0.123 | 0.178 |
| Average Delay (TAD) | 7.90 | 11.38 | 17.51 |
| Throughput (S) | 0.302 | 0.351 | 0.411 |
| $P(t \le 1)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 5a

BASIC ALOHA

| 5% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.181 | 0.330 | 0.451 |
| Average Delay (TAD) | 10.08 | 21.16 | 34.71 |
| Throughput (S) | 0.082 | 0.134 | 0.165 |
| $P(t \leq 1)$ | 0.9999999 | 0.9999849 | 0.9996504 |
| $P(t \leq 2)$ | 0.9999999 | 0.9999999 | 0.9999998 |
| $P(t \leq 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 5b

BASIC ALOHA

| 5% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.484 | 0.551 | 0.632 |
| Average Delay (TAD) | 39.48 | 51.25 | 71.45 |
| Throughput (S) | 0.171 | 0.180 | 0.184 |
| $P(t \leq 1)$ | 0.9992920 | 0.9974360 | 0.9898141 |
| $P(t \leq 2)$ | 0.9999995 | 0.9999934 | 0.9998962 |
| $P(t \leq 3)$ | 0.9999999 | 0.9999999 | 0.9999989 |
| $P(t \leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 5c

SLOTTED ALOHA

| 5% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.095 | 0.181 | 0.259 |
| Average Delay (TAD) | 4.31 | 9.08 | 14.34 |
| Throughput (S) | 0.090 | 0.164 | 0.222 |
| P(t≤1) | 0.9999999 | 0.9999999 | 0.9999987 |
| P(t≤2) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤3) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤4) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤5) | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 5d

SLOTTED ALOHA

| 5% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.282 | 0.330 | 0.3934 |
| Average Delay (TAD) | 16.09 | 20.16 | 26.60 |
| Throughput (S) | 0.238 | 0.268 | 0.303 |
| P(t≤1) | 0.9999969 | 0.9999849 | 0.9999111 |
| P(t≤2) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤3) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤4) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤5) | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 5e

SLOTTED ALOHA WITH CAPTURE

| 5% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.050 | 0.099 | 0.148 |
| Average Delay (TAD) | UNKNOWN | UNKNOWN | UNKNOWN |
| Throughput (S) | 0.095 | 0.180 | 0.256 |
| P(t≤1) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤2) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤3) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤4) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤5) | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 5f

SLOTTED ALOHA WITH CAPTURE

| 5% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.163 | 0.196 | 0.242 |
| Average Delay (TAD) | UNKNOWN | UNKNOWN | UNKNOWN |
| Throughput (S) | 0.277 | 0.322 | 0.379 |
| P(t≤1) | 0.9999999 | 0.9999999 | 0.9999993 |
| P(t≤2) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤3) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤4) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤5) | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 5g

CSMA NONPERSISTENT

| 5% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.091 | 0.167 | 0.231 |
| Average Delay (TAD) | 8.10 | 16.20 | 24.30 |
| Throughput (S) | 0.091 | 0.167 | 0.231 |
| $P(t \le 1)$ | 0.9999999 | 0.9999999 | 0.9999996 |
| $P(t \le 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 5h

CSMA NONPERSISTENT

| 5% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.249 | 0.286 | 0.333 |
| Average Delay (TAD) | 26.81 | 32.40 | 40.50 |
| Throughput (S) | 0.249 | 0.286 | 0.333 |
| $P(t \le 1)$ | 0.9999991 | 0.9999964 | 0.9999831 |
| $P(t \le 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 5i

CSMA 1-PERSISTENT

| 5% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.009 | 0.036 | 0.075 |
| Average Delay (TAD) | 0.77 | 3.00 | 6.54 |
| Throughput (S) | 0.099 | 0.193 | 0.278 |
| $P(t\leq1)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 5j

CSMA 1-PERSISTENT

| 5% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.089 | 0.123 | 0.178 |
| Average Delay (TAD) | 7.90 | 11.38 | 17.51 |
| Throughput (S) | 0.302 | 0.351 | 0.411 |
| $P(t\leq1)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 6a

BASIC ALOHA

| 10% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.181 | 0.330 | 0.451 |
| Average Delay (TAD) | 10.08 | 21.16 | 34.71 |
| Throughput (S) | 0.082 | 0.134 | 0.165 |
| $P(t \le 1)$ | 0.9999999 | 0.9999849 | 0.9996504 |
| $P(t \le 2)$ | 0.9999999 | 0.9999999 | 0.9999998 |
| $P(t \le 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 6b

BASIC ALOHA

| 10% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.484 | 0.551 | 0.632 |
| Average Delay (TAD) | 39.48 | 51.25 | 71.45 |
| Throughput (S) | 0.171 | 0.180 | 0.184 |
| $P(t \le 1)$ | 0.9992920 | 0.9974360 | 0.9898141 |
| $P(t \le 2)$ | 0.9999995 | 0.9999934 | 0.9998962 |
| $P(t \le 3)$ | 0.9999999 | 0.9999999 | 0.9999989 |
| $P(t \le 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \le 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 6c

SLOTTED ALOHA

| 10% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.095 | 0.181 | 0.259 |
| Average Delay (TAD) | 4.31 | 9.08 | 14.34 |
| Throughput (S) | 0.090 | 0.164 | 0.222 |
| $P(t \leq 1)$ | 0.9999999 | 0.9999999 | 0.9999987 |
| $P(t \leq 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 6d

SLOTTED ALOHA

| 10% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.282 | 0.330 | 0.393 |
| Average Delay (TAD) | 16.09 | 20.16 | 26.60 |
| Throughput (S) | 0.238 | 0.268 | 0.303 |
| $P(t \leq 1)$ | 0.9999969 | 0.9999849 | 0.9999111 |
| $P(t \leq 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t \leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 6e

SLOTTED ALOHA WITH CAPTURE

| 10% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.050 | 0.099 | 0.148 |
| Average Delay (TAD) | UNKNOWN | UNKNOWN | UNKNOWN |
| Throughput (S) | 0.095 | 0.180 | 0.256 |
| $P(t\leq 1)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

Table 6f

SLOTTED ALOHA WITH CAPTURE

| 10% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.163 | 0.196 | 0.242 |
| Average Delay (TAD) | UNKNOWN | UNKNOWN | UNKNOWN |
| Throughput (S) | 0.277 | 0.322 | 0.379 |
| $P(t\leq 1)$ | 0.9999999 | 0.9999999 | 0.9999993 |
| $P(t\leq 2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq 5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 6g

CSMA NONPERSISTENT

| 10% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.091 | 0.167 | 0.231 |
| Average Delay (TAD) | 8.10 | 16.20 | 24.30 |
| Throughput (S) | 0.091 | 0.167 | 0.231 |
| $P(t\leq1)$ | 0.9999999 | 0.9999999 | 0.9999996 |
| $P(t\leq2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 6h

CSMA NONPERSISTENT

| 10% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.249 | 0.286 | 0.333 |
| Average Delay (TAD) | 26.81 | 32.40 | 40.50 |
| Throughput (S) | 0.249 | 0.286 | 0.333 |
| $P(t\leq1)$ | 0.9999991 | 0.9999964 | 0.9999831 |
| $P(t\leq2)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq3)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq4)$ | 0.9999999 | 0.9999999 | 0.9999999 |
| $P(t\leq5)$ | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 6i

CSMA 1-PERSISTENT

| 10% Distress | G=0.1 | G=0.2 | G=0.3 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.009 | 0.036 | 0.075 |
| Average Delay (TAD) | 0.77 | 3.00 | 6.54 |
| Throughput (S) | 0.099 | 0.193 | 0.278 |
| P(t≤1) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤2) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤3) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤4) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤5) | 0.9999999 | 0.9999999 | 0.9999999 |

TABLE 6j

CSMA 1-PERSISTENT

| 10% Distress | G=0.331 | G=0.4 | G=0.5 |
|---|---|---|---|
| Prob of Delay (PC1) | 0.089 | 0.123 | 0.178 |
| Average Delay (TAD) | 7.90 | 11.38 | 17.51 |
| Throughput (S) | 0.302 | 0.351 | 0.411 |
| P(t≤1) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤2) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤3) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤4) | 0.9999999 | 0.9999999 | 0.9999999 |
| P(t≤5) | 0.9999999 | 0.9999999 | 0.9999999 |

In order to determine the effect of general calling on a single DSC channel, the number of general calls, navigational calls, and distress calls must first be determined from the given channel loading figure. The number of navigational calls is assumed to be 90% of total general calls. This is derived from the calling statistics given in the IWP paper. Distress calling is assumed to be 1% of the commercial calls (general + navigational calls). Based on these assumptions, the total channel loading can be broken down into the following:

Load Total (LT) = Load (lgen) + Load (lnav) + Load (ldist)

$$LT = \frac{(Gcall)(4)(0.57)}{3600} + \frac{(Ncall)(4)(0.57)}{3600} + \frac{(Dcall)(10)(0.38)}{3600}$$

$$LT = Gcall(.0006333) + Ncall(.0006333) + Dcall(.0010555)$$

$$Ncall = (0.9)Gcall$$

$$Dcall = (0.01)(Gcall + Ncall) = (0.01)(Gcall + (0.9)(Gcall))$$
$$= (0.01)Gcall + (0.009)(Gcall)$$

$$LT = Gcall(.0006333)+(.9)(Gcal(.0006333)+(.01)Gcal+(.009)Gcal$$

$$Gcall = LT / 0.0012234$$

Gcall = 0.1 / 0.0012234 = 81 General calls = 324 DSC seq

Ncall = (0.9)(Gcall) = 72 Nav calls = 288 DSC seq

Dcall = (0.01)(Gcall + Ncall) = 1 Distress call = 10 DSC seq

Assuming a 2 to 1 ratio for ship to shore radio traffic, the total calling is broken down into the following:

Total Gcall = 81

Shore Gcall = 27

Ship Gcall = 54

Total Ncall = 72

Shore Ncall = 24

Ship Ncall = 48

Dcall = 1

If a calling channel had only general calling allowed on it, the probability that a general call DSC sequence will cause a collision with another general call DSC sequence is:

PS10 = S / Lgen where S = throughput due to general calls
Lgen = load due to general calls

= 0.046 / 0.051

PS10 = .903

PC10 = 1 - .903 = 0.097

Disciplined access will take place for only the shore station calls plus 30% of the ship station calls [Ref. 4:p. 19]. The total disciplined calls will, therefore, be 43.

This means that 38 general calls enter the calling system in a random manner. The probability that a general DSC sequence is destroyed by a randomly entering general call DSC sequence is:

PS11 = S / Lgen-r    where S = throughput due to random calls
                           Lgen-r = load due to random calls

= 0.023 / 0.024

= 0.953

PC11 = 1 - PS11 = 0.047

The total probability of losing a general call DSC sequence is then:

PC12 = PC10 + ( 1 - PC10 )(PC11) = 0.139

If the calling channel is also used for navigational calling, 70% of both shore and ship navigational calls (50) are regarded as entering the system randomly as these calls are generated by ship stations or low range shore-based stations. Therefore, a total of 88 general and navigational calls will be accessing the calling channel randomly. The probability that a randomly entering commercial (general and navigational) call DSC sequence will destroy another commercial call DSC sequence is:

PS13 = S / Lcomm    where S = throughput due commercial calls
                           Lcomm = load due commercial calls

= 0.080 / 0.097

$PS13 = 0.824$

$PC13 = 1 - PS13 = 0.176$

The probability that this commercial call DSC sequence is destroyed by another commercial call DSC sequence that has entered the system randomly is:

$$PS14 = S \; / \; L_{comm-r}$$
$$= 0.050 \; / \; 0.056$$
$$= 0.895$$

$PC14 = 1 - PS14 = 0.105$

The total probability of losing a commercial call DSC sequence is calculated to be:

$$PC15 = PC13 + (1 - PC13)(PC14) = 0.263$$

If a calling channel was designed for both commercial and distress calling, the effect of combining all calls onto one channel should be determined. The probability that a commercial call is in progress when a distress call is initiated is the same calculation as PC13:

$PC16 = 0.176$

The probability that another commercial call DSC sequence will randomly enter the system is the same as PC14:

$PC17 = 0.105$

The combined probability that a distress call will be destroyed by any type of commercial call DSC sequence is the same as PC15:

PC18 = 0.263

Because a complete distress call attempt consists of ten DSC sequences, the probability of collision for the whole distress call attempt by a commercial DSC sequence is:

$$PC19 = (PC18)^{10} = 0.00000158$$

If only distress calls are allowed on the channel, the probability that any two distress call DSC sequences would destroy each other is:

$$\begin{aligned} PS20 &= S \ / \ Ldis \\ &= 0.00210 \ / \ 0.00211 \\ &= 0.996 \end{aligned}$$

$$PC20 = 1 - PS20 = 0.004$$

Finally, in the case of a combined commercial calling and distress channel, the additional or marginal loss of distress call attempts because of commercial calling on the channel is:

$$PC21 = PC20 + ( 1 - PC20 ) (PC19) - PC20 = 0.00000158$$

# VI. CONCLUSIONS AND RECOMMENDATIONS

## A. CONCLUSIONS

This thesis has presented a model of a VHF-FM Digital Selective Calling (DSC) system using grade of service as a criterion to ascertain if a single DSC channel could accommodate both distress and commercial calling. Although the Interim Working Party (IWP) 8/10 model does use one grade of service factor, probability of delay, the author's model takes into account several grade of service parameters, which lend a greater credibility to its conclusions. The author's proposed model calculates the probability of a call being delayed, the average delay of a call, the probability of a call being answered within a certain time frame, and the throughput for the random access calling systems of ALOHA, Slotted ALOHA, Slotted ALOHA with Capture, Nonpersistent CSMA, and 1-Persistent CSMA. Based on the results of these calculations, as presented in Chapter V, one DSC channel is capable of accommodating all distress and commercial calling. In addition, 1-Persistent CSMA was found to be superior to all the other random access calling systems evaluated. These results concur with and strengthen the IWP model.

There are three factors that support the author's conclusions. The first is, for channel loading conditions ranging from 0.1 to 0.5 Erlangs, 1-Persistent CSMA

consistently has the lowest probability of delay out of all the different calling systems. The maximum probability of delay encountered for 1-Persistent CSMA was 0.178 at a channel loading of 0.5 Erlangs. The CCIR Interim Working Party (IWP) 8/10 model regarded a probability of delay of 0.19 as reasonable [Ref. 4:p. 20]. As such, in the author's

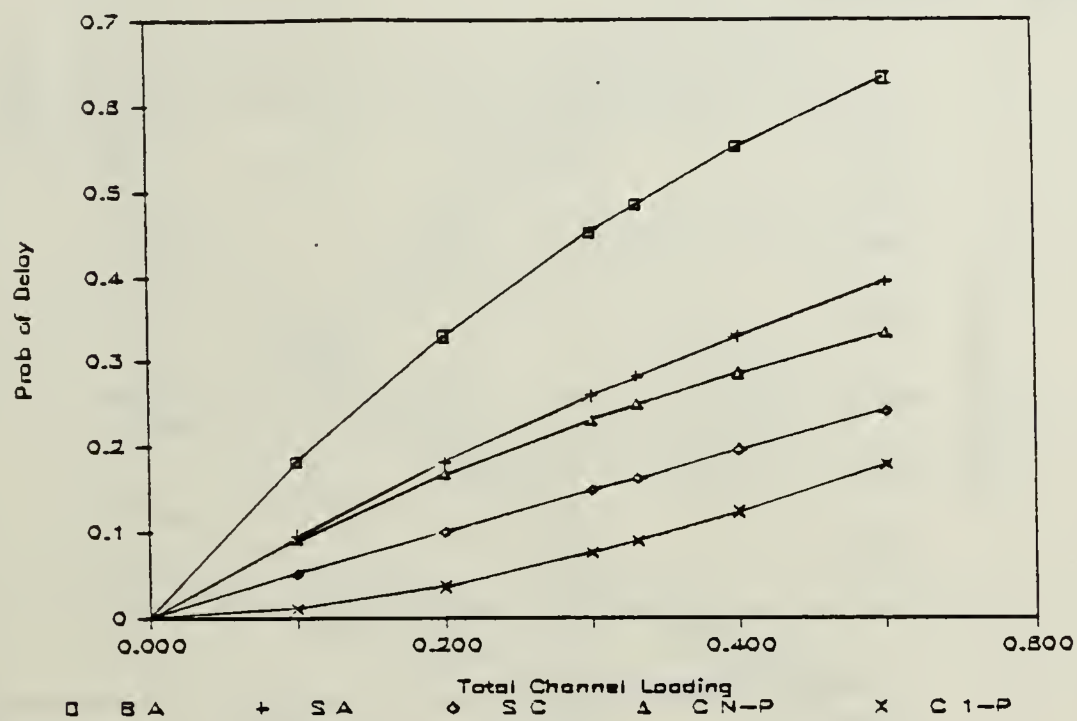



Figure 14. Probability of Delay Versus Channel Loading

opinion, the probability of delay in the 1-Persistent CSMA system is acceptable for a combined distress and commercial calling channel. The probability of delay versus channel loading for the random access calling systems is plotted in Figure 14. The following abbreviations will be used in figures 14, 15, and 16: BA (Basic ALOHA), SA (Slotted

ALOHA), SC (Slotted ALOHA with Capture), C N-P (Nonpersistent CSMA), and C 1-P (1-Persistent CSMA).

The second factor is that the average delay of a call for 1-Persistent CSMA, as channel loading varies from 0.1 to 0.5 Erlangs, is also the lowest of all the systems examined. Figure 15 shows a plot of the average delay as a function of channel loading.

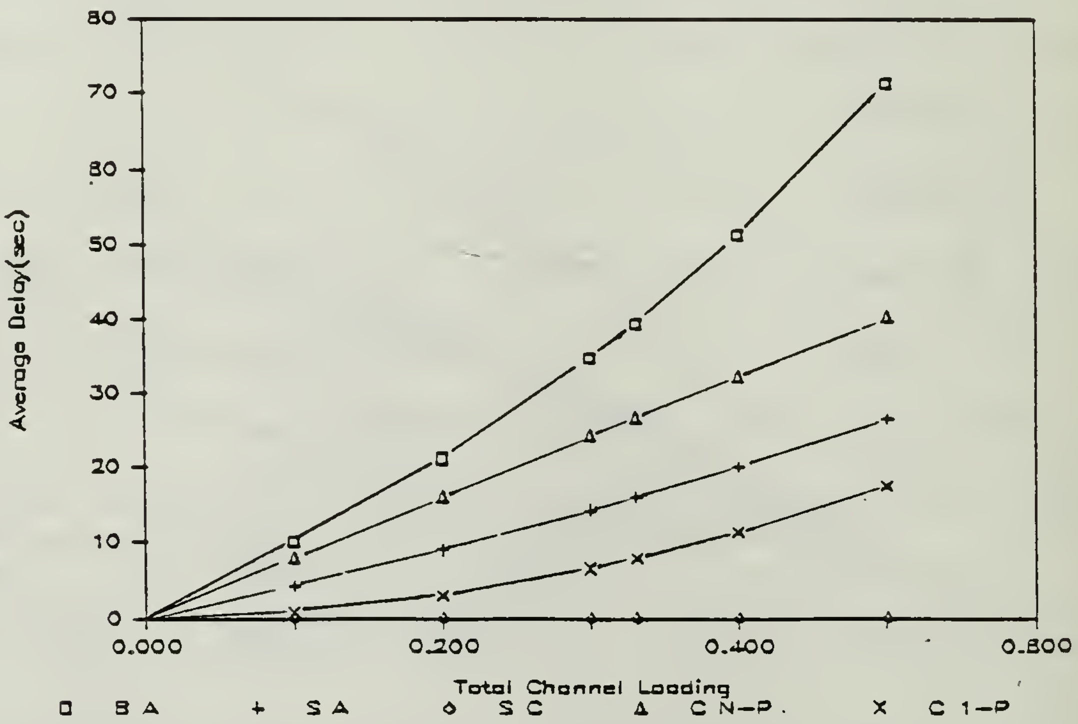



Figure 15. Average Delay Versus Channel Loading

The maximum channel loading limitation of 0.1 Erlangs, imposed by the International Maritime Organization (IMO) and used as the basis for the IWP model, should not be the primary criterion used to dictate the required number of calling channels. Figures 14 and 15 indicate that a channel

can be loaded to 0.5 Erlangs and still remain within acceptable levels for probability of delay and average delay of a 1-Persistent CSMA random access calling system.

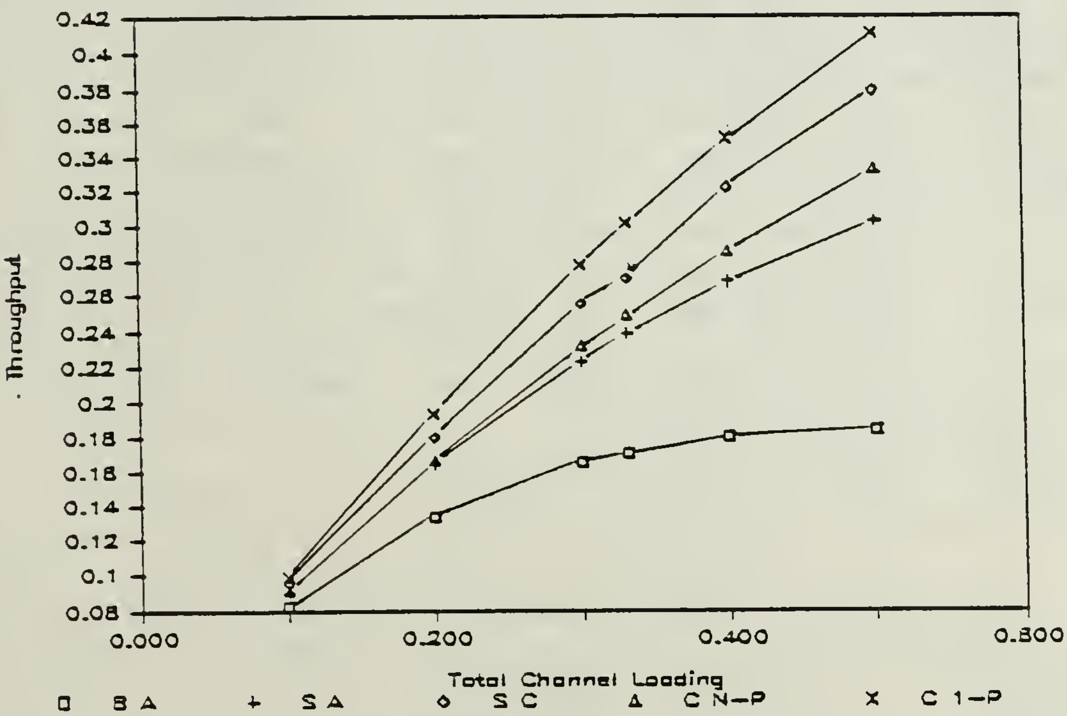



Figure 16. Throughput Versus Channel Loading

Thirdly, the 1-Persistent CSMA random access calling system has the highest throughput, for channel loading between 0.1 and 0.5 Erlangs, of any of the systems studied. As shown in Figure 16, throughput for 1-Persistent CSMA continually betters the other random access calling systems.

In the author's opinion, there are two criteria that do not affect the selection of a random access calling system. First, the probability of a distress call being answered within the 1 to 5 minute time frame does not appreciably

change among the systems analyzed. Nor does this probability change as channel loading is varied from 0.1 to 0.5 Erlangs. The calculations of Chapter V show the probabilities that a call will be answered within 1 minute of the initial transmission range from 0.9996 to 0.9999. The other criterion that does not affect the random access calling system selection is the amount of distress traffic on the channel. Percentages of distress traffic from 1 to 10 percent were analyzed and no changes in the delay or throughput figures were noted.

No matter which grade of service factors are considered, the 1-Persistent CSMA random access calling system is consistently superior. Its low probability of a call being delayed, low average delay of a call, and relatively high throughput show, in the author's opinion, that it is reasonable to use 1-Persistent CSMA and combine distress and commercial calls onto a single VHF-FM Digital Selective Calling (DSC) System channel.

## B. RECOMMENDATIONS

Based on the conclusions presented above, it is recommended that a single VHF-FM DSC channel be used for both distress and commercial calling. In addition, 1-Persistent Carrier Sense Multiple Access should be chosen as the radio communications method used for transmitting the DSC call sequences. The International Radio Consultative Committee

(CCIR) or the International Maritime Organization (IMO) must designate appropriate grade of service levels as these levels could be instrumental in determining the required number of DSC calling channels. For example, the CCIR or IMO could have a difference in opinion from that of the author's and determine that the maximum average delay for a call should be less than five seconds. This fact would cause more than one channel to be designated as distress and calling channels because the Erlang channel loading on a single channel would be a limited. It is also recommended that the actual percentage of distress calling to total calling be determined in order to validate the model.

Finally, a cost-benefit evaluation should be conducted for each of the random access calling methods. Although the 1-Persistent CSMA technique theoretically indicates superiority to the other methods, it may not be economically feasible. An approach to the study would be to look at the marginal value - marginal cost relationship among the different systems. For example, at the projected worst-case channel loading of 0.331 Erlangs, the throughput of the Slotted ALOHA with Capture system is 27.7% of the total offered traffic. The throughput for 1-Persistent CSMA at the same channel loading is 30.2% of the total offered traffic. If the cost was significantly higher to obtain the 1-Persistent CSMA technology, the additional 2.3% in throughput

may not be justified. The cost-performance trade-offs must be examined, not only for each random access calling systems as a whole, but for each of the desired levels of grade of service. Even though the throughput of the Slotted ALOHA with Capture example above was only 2.3% below 1-Persistent CSMA, the accompanying probability of delay was almost doubled.

The maritime mobile service will benefit greatly from the Digital Selective Calling (DSC) system when it is in place and operating. This thesis has presented a means to help ensure that the DSC system is properly designed.

## LIST OF REFERENCES


1. Johnson, E., Kump, C., and Turner, E., Maritime Mobile Digital Selective Calling: Equipment Development and Operational Test. Prepared by GTE Sylvania, Inc. Mountain View: GTE Sylvania, Inc., 1974

2. International Radio Consultative Committee (CCIR) Report 908 (DRAFT), Channel Requirements For A Digital Selective Calling System, 1 June 1984.

3. Jansen, T. "Digital SELCALL: Calling and Emergency System for Short-Wave Radio," Telektronikk (Norway), Vol. 79, No. 1., 1983, Written in Norwegian.

4. International Radio Consultative Committee (CCIR), Report Of The Third Meeting of Interim Working Party 8/10. 12 November 1984.

5. Bieser, A. H., "An Antenna Pedestal For Shipboard Satellite Terminals," Symposium Papers RTCM Assembly Meeting, Vol. 1, Satellite Communications/Automated Systems., Washington, D.C.: Radio Technical Commission for Marine Services, 1981, part 1E.

6. Parker, J.D., "Development of Automatic Maritime Radio Telephone Systems in Europe," Symposium Papers RTCM Assembly Meeting, Vol. 1, Satellite Communications/Automated Systems. Washington, D.C.: Radio Technical Commission for Marine Services, 1981, part 1G pp. 1-14.

7. Bunce, R. G., "Preparing for Data Communications on Marine Satellite/VHF Radio/SITOR," Symposium Papers RTCM Assembly Meeting, Vol. 1, Satellite Communications/Automated Systems. Washington, D.C.: Radio Technical Commission for Marine Services, 1981, part 1B, p. 7.

8. Lundberg, O., "The International Maritime Satellite Organization (INMARSAT)," Symposium Papers RTCM Assembly Meeting, Vol. 1, Satellite Communications/Automated Systems. Washington, D.C.: Radio Technical Commission for Marine Services, 1981, part 1A pp. 1-11.

9. Einis, L., An Analysis to Determine the Feasibility of COMSAT Corporation Subsidy to Assist in Improving Communications Interoperability Between U.S. Navy/U.S. Flag Merchant Ships, M.S. Thesis, Naval Postgraduate School, Monterey, California, March 1984.

10. Maritime Administration, U.S. Department of Commerce Report MTR-7217, Rev. 2, Maritime Digital Selective Calling System Technical Description, by T. D. Haas and J. J. Fee, October 1978.

11. Federal Communications Commission, "Digital Selective Calling System in the Maritime Mobile Service," Further Notice of Proposed Rule Making: PR Docket No. 84-499. Government Printing Office, Washington, D.C., 26 October 1984.

12. Hempton, G. F., "The Future Global Maritime Distress and Safety System", Symposium Papers RTCM Assembly Meeting, Vol. 1, Satellite Communications/Automated Systems. Washington, D.C.: Radio Technical Commission for Marine Services, 1981, part 1H, pp. 1.

13. International Radio Consultative Committee (CCIR), Interim Working Party 8/10 Digital Selective Calling Coordinations of Trials Report to Study Group 8, 15 February 1984.

14. International Radio Consultative Committee (CCIR), "Digital Selective-Calling System For Use In The Maritime Mobile Service," Recommendation 493-2 (DRAFT), 1 June 1984.

15. International Radio Consultative Committee (CCIR), "Operational Procedures For The Use Of Digital Selective-Calling (DSC) Equipment In The Maritime Mobile Service," Recommendation 541-1 (MOD I) (DRAFT), modifications made May 1984, p. 205.

16. Tanenbaum, A. S. Computer Networks. Englewood Cliffs: Prentice-Hall, Inc., 1981.

17. Abramson, N., "The ALOHA System - Another Alternative for Computer Communications," Proc. FJCC, pp.281-285, 1970.

18. Abramson, N., "The Throughput of Packet Broadcasting Channels," IEEE Transactions On Communications, Vol. COM-25, pp. 117-128, 1977.

19. Rosner, R. D., Packet Switching. Belmont: Lifetime Learning Publications, 1982.

20. Stallings, W., Data and Computer Communications. New York: Macmillan Publishing Company, 1985.

21. Roberts, L., "Extensions of Packet Communication Technology to a Hand Held Personal Terminal," Proc. SJCC, pp. 295-298, 1972.

22. Tobagi, Fouad A. "Multiaccess Protocols in Packet Communication Systems," IEEE Transactions On Communications, Vol. COM-28, No. 4., 1980, pp. 468-488.

23. Kleinrock, L., and Tobagi, F. A., "Packet Switching in Radio Channels: Part 1 - Carrier Sense Multiple-Access Modes and Their Throughput-Delay Characteristics," IEEE Transactions on Communications, v. COM-23, No. 12, December 1975.

24. Kleinrock, L. Queueing Systems Volume I: Theory. New York: John Wiley & Sons, 1975.

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